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SEDIMENTOLOGY, DEPOSITIONAL ARCHITECTURE, AND DIAGENESIS OF THE CAYMAN FORMATION AT TARPON SPRINGS ESTATES, GRAND CAYMAN, BRITISH WEST INDIES

by

Jason Christopher Montpetit ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department of Geology

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"Imagination is more important than knowledge."

- Albert Einstein

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance a thesis entitled SEDIMENTOLOGY, DEPOSITIONAL ARCHITECTURE, AND DIAGENESIS OF THE CAYMAN FORMATION, GRAND CAYMAN, BRITISH WEST INDIES submitted by JASON CHRISTOPHER MONTPETIT in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

The Cayman Formation (Middle Miocene) on Grand Cayman is formed of fabric retentive and fabric destructive microcrystalline dolostones. In the Tarpon Springs area, this formation is divided into units I to III. Each unit, which represents a distinct depositional regime, is bounded by discontinuities. These depositional units incorporate sediments that were deposited on the southern windward margin of an open bank.

The complex diagenetic fabrics preserved in the study area are a product of fluctuating sea levels and paleowater tables that have affected the strata since the Late Miocene. Periods of subareal exposure have resulted in meteoric and vadose cementation, dissolution, poikilotopic calcite-dolomite fabrics, calcretization and karst development. Subareal exposure associated with the Messinian lowstand resulted in the development of the Cayman Unconformity, a high relief disconformable surface on top of the Cayman Formation. Subsequent transgressions led to the formation of marine cementation, bioerosion, pervasive matrix dolomitization and recrystallization.

DEDICATION

To my father, Jack Montpetit, for doing what was best for his family instead of his career. Thanks Dad.

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Chapter 1

Introduction

1.1 Location

Grand Cayman, Cayman Brac and Little Cayman are British Protectorates situated in the northern part of the Caribbean Sea between 19°15' and 19°45' North and 74°44' and 81°27' West (Figure 1.1A). These islands are situated on the Cayman Ridge which composes the northern margin of the Cayman Trench.

1.2 Climate

Grand Cayman's small size and low-lying nature precludes the island from exerting a strong control on its climatic regime (Blanchon, 1995). The island's climate is modified by the Caribbean Sea, which results in high humidities, restricted air temperatures and relatively stable weather patterns (Burton, 1994). Preciptation patterns across the island exhibit considerable variation. Rainfall increases from east to west reflecting convection cloud development (Burton, 1994), with the west side and southwest corner receiving the greatest amount of precipitation (Ng, 1990). The year can be divided into a wet season and a dry season. The latter, from November to April, averages less than 8 cm/month whereas the former, from May to October, is characterized by 12 -15 cm/month (Sauer, 1982). Associated with the wet season are higher air temperatures as compared to the dry season. Cooler temperatures during the dry season are associated with cold fronts that produce strong winds from the northwest (Nor'westers), which typically last 2 - 3 days.

1.3 Topography

Grand Cayman is a low lying island with a maximum elevation that rarely exceeds 6 m above sea level (asl). Exceptions to this include "The Mountain" in the north central

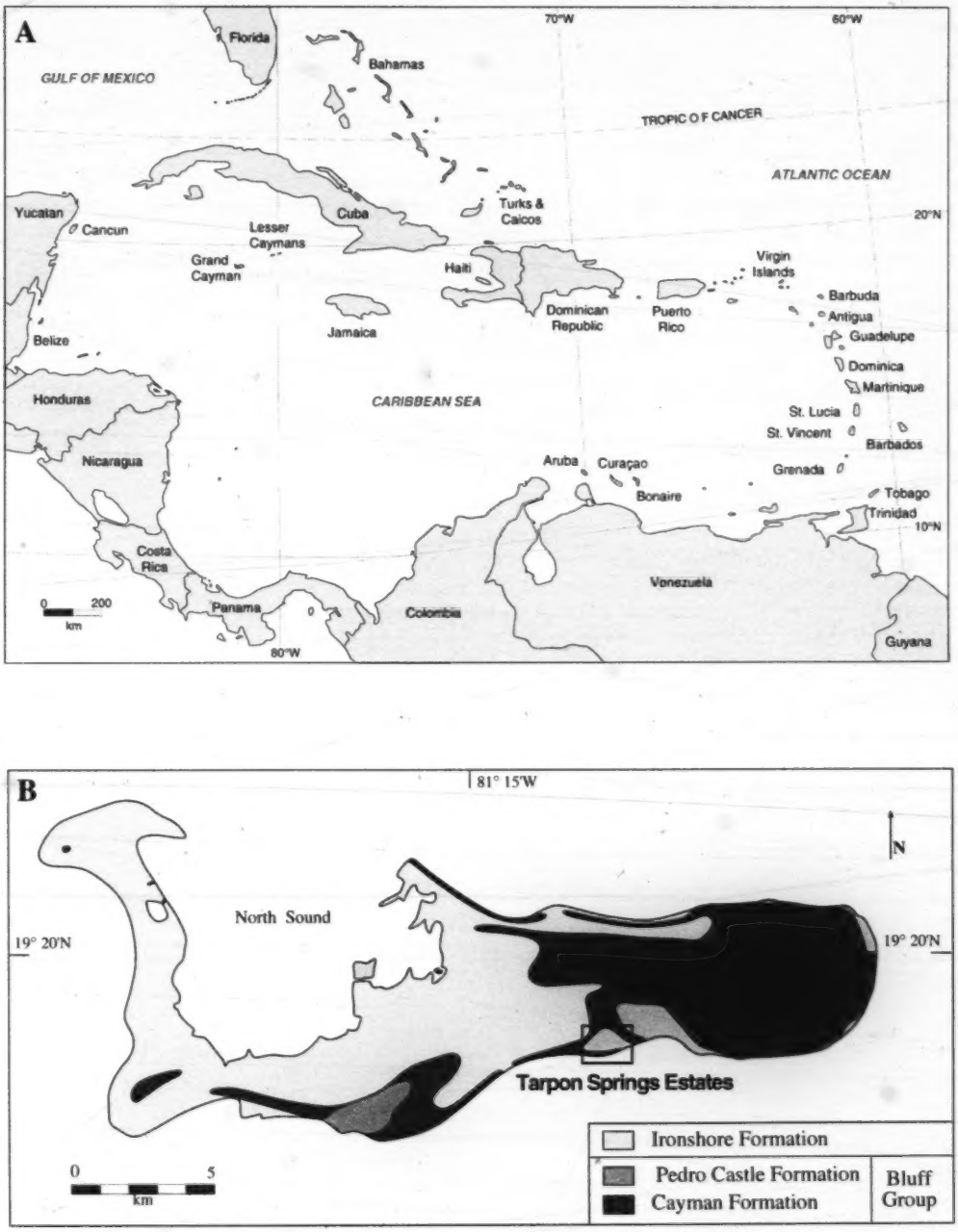

Figure 1.1: Study Area Location (A) Grand Cayman's location in the Caribbean Sea, modified from Blanchon (1995). (B) Surficial geology of Grand Cayman, modified from Jones and Hunter, 1994a).

part of the island which approaches 20 m asl (Squair, 1988) and elevated areas around Pedro Castle. Elevations in excess of 6 m asl are attained by the peripheral ridge that parallels the north, east and south coasts of the island. Topographic highs are underlain by dolostones of the Bluff Group that display well developed karst features (Stoddart, 1980; Squair, 1988). Lower lying areas, which are covered by mangrove swamps, are commonly underlain by limestones of the Ironshore Formation (Figure 1.1B).

1.4 Tectonic setting

Grand Cayman is an exposed prominance of the Cayman Ridge (Uchupi, 1975) (Figure 1.2). Extending east - northeast across the Caribbean from southeast Cuba to the Yucatan Basin, the Cayman Ridge has a double ridged crest, 50 - 80 km wide separated by small perched valleys, basins and flats (Holcombe *et al.*, 1990). Convergence of the North American and Caribbean plates during the Late Cretaceous led to the creation of an intra-oceanic island arc. Dredged samples recovered from the Cayman Ridge at depths in excess of 2500 m consist primarily of granodiorites, tonalites, and basalts. These crystalline basement rocks (Perfit and Heezen, 1978) are characteristic of an Island Arc setting (Ladd *et al.*, 1990). Although subduction ceased during the Late Cretaceous with closure of the subduction zone, diminished volcanism continued until Late Eocene - Oligocene time. Subsidence appears to have been initiated during the Miocene. Samples collected from depths above 2500 m consist primarily of shallow water carbonates and to a lesser extent volcanics and clastics. Based on this relationship, Perfit and Heezen (1978) proposed a subsidence rate in excess of 6 cm/Ka. This rate is not characteristic of the entire Cayman Ridge. On Grand Cayman an exploratory well drilled 401 m bsl, terminated in Oligocene limestones. Utilizing these results Emery and Milliman (1980) proposed a subsidence rate of 0.1 to 1.3 cm/Ka for Grand Cayman. These contrasting rates proposed for the Cayman Ridge (Perfit and Heezen, 1978) and Grand Cayman (Emery and Milliman, 1980) suggest that subsidence and/or uplift was a localized feature.

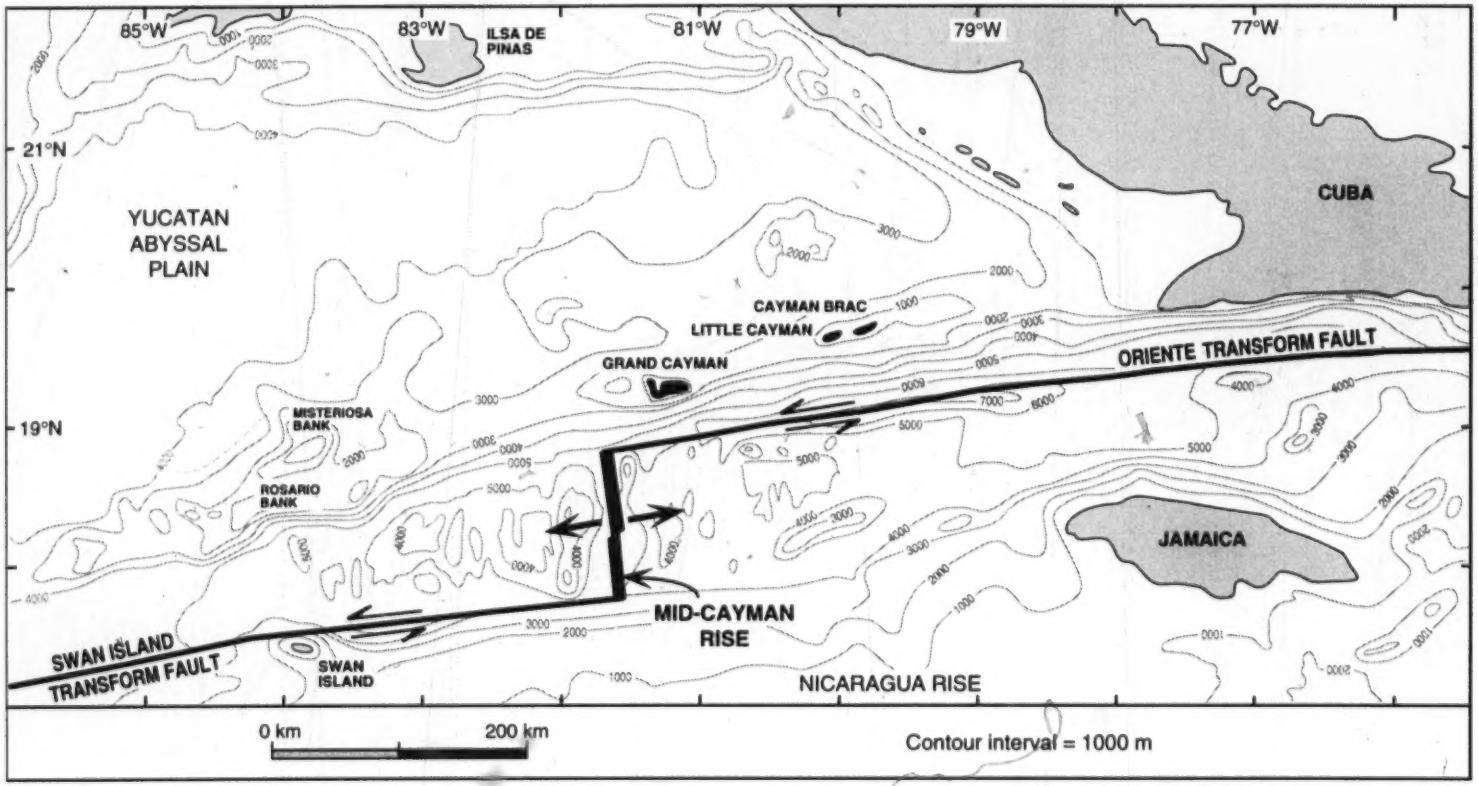

Figure 1.2: Tectonic setting of the Cayman Islands (modified from Pleydell *et al.*, 1990)

Age and elevation differences between the exposed strata of Cayman Brac and Grand Cayman implies that differential movement has taken place in the past. This apparent movement and the apparent tilting (0.5° west) of Cayman Brac indicates that each island is situated on an independant fault block (Woodroffe *et al.*, 1983; Woodroffe, 1988; Jones and Hunter, 1990). The position and elevations of Pleistocene reefs are similar on each of the Cayman Islands. Consequently differential movement between the independant fault blocks has not taken place in the last 125,000 years (Woodroffe, 1988; Jones and Hunter, 1990).

1.5 Stratigraphy

The stratigraphy of the Tertiary succession of the Cayman Island's was first described by Matley (1924, 1925a, 1925b, 1926). The core of each island is the Bluff Limestone (Matley, 1926) which is a massive, hard, white microcrystalline carbonate. The use of the term "Limestone" is misleading because this carbonate is composed predominantly of dolostone (Jones and Hunter, 1989; Ng, 1990; Pleydell, 1987; 1990). Consequently, Jones and Hunter (1989) used the name Bluff Formation in order to remove the lithological connotation attached to the original name. Subsequently, Jones *et al.*, (1994b) elevated the Bluff Formation to group status. The Bluff Group is composed of the disconformably bounded Brac Formation, Cayman Formation, and Pedro Castle Formation (Figure 1.3).

The Lower Oligocene Brac Formation is composed of limestone and massive sucrosic dolostone that contains isolated pods of limestone. Exposures are limited to the sea cliffs at the east end of Cayman Brac. This Formation, estimated to be at least 33 m thick on Cayman Brac, has not yet been located on Grand Cayman or Little Cayman. The wackestones to grainstones that form this formation contain numerous *Lepidocyclina* and lesser numbers of other foraminifera, red algae, and echinoid plates (Jones *et al.*, 1994a; Jones and Hunter, 1994a; Hunter, 1994). These carbonates accumulated in a

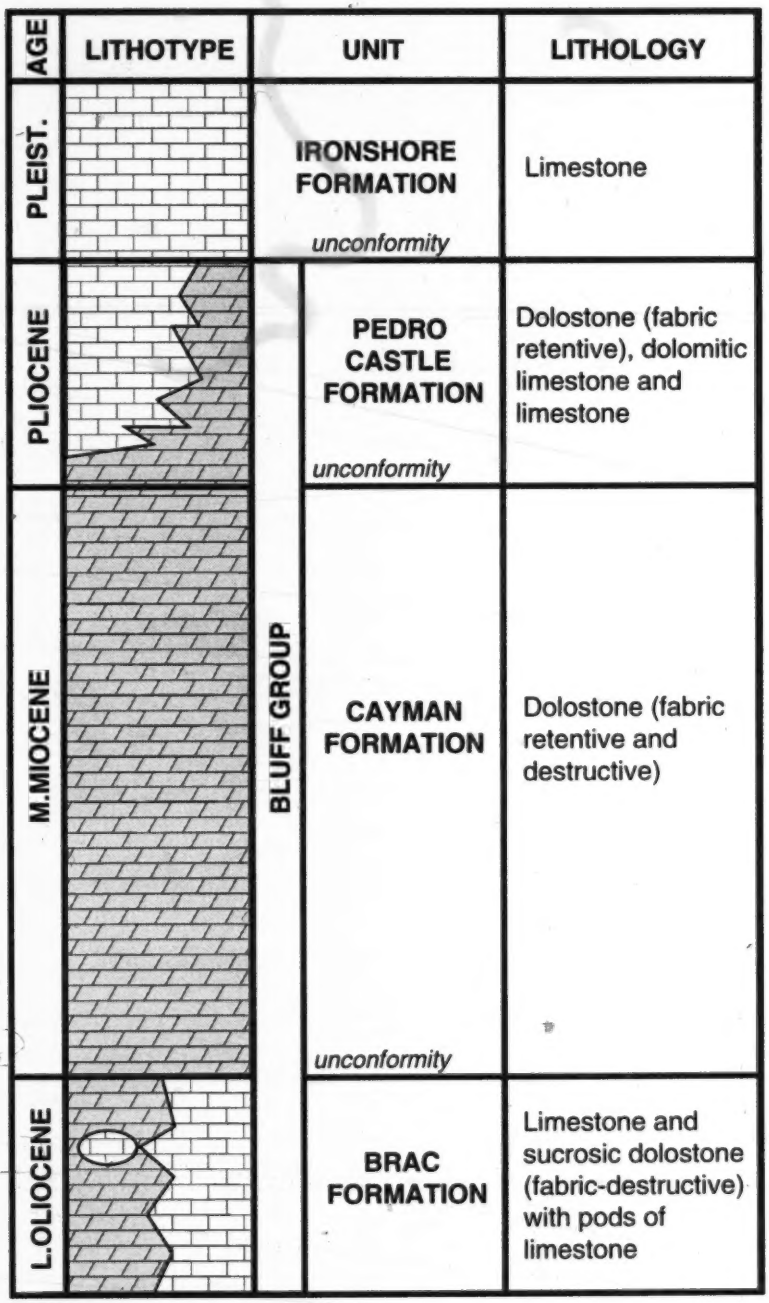

Figure 1.3: Stratigraphic column of the Cayman Islands (modified from Jones *et al.*, 1994b).

shallow water environment devoid of large scale reefal development.

The age of the Brac Formation was initially determined utilizing foraminifera biostratigraphy. Abundant *Lepidocyclina*, including eight recognizable species led Vaughan (1926) and Matley (1926) to propose a Middle Oligocene (Rupelian) age for the strata. This genus of foraminifera has been shown to span the entire Oligocene in the Caribbean (Cole, 1957). The Oligocene can be divided in the Caribbean using the foraminifera *Miogypsina.* This genus is restricted to the Upper Oligocene in the Caribbean (Cole, 1957; 1958). The absence of *Miogypsina* in the Brac Formation suggests a Lower Oligocene age. Radiometric dating utilizing an average $^{87}Sr/^{86}Sr$ ratio derived from five limestone samples (0.70808), indicates an age of approximately 28 million years (Jones *et al.*, 1994a) which is consistent with a late Lower Oligocene (Rupelian) age.

The lower boundary of the Brac Formation is not exposed. The boundary between the Brac Formation and the overlying Cayman Formation is a disconformity. Topographic relief developed on this surface is at least 25 m. This disconformity represents a period of subaerial exposure that may have lasted from the Upper Oligocene to the earliest Miocene (Jones *et al.*, 1994a).

The Cayman Formation is well exposed on Cayman Brac, Grand Cayman, and Little Cayman. Strata are composed of fabric retentive and destructive microcrystalline dolostones (Jones *et al.*, 1984; Pleydell, 1987; Ng, 1990; Hunter, 1994; Jones, 1994; Wignall, 1995), that contain a diverse coral fauna which is dominated by branching (e.g., *Porites* and *Stylophora*) and massive corals (e.g., *Montastrea*, *Porites, Diploria*). Besides corals, these mudstones to rudstones contain numerous foraminifera (dominated by *Amphistegina*), red algae, *Halimeda,* and gastropods (Jones, 1994; Hunter, 1994). On Cayman Brac the lower part of the formation is dominated by coralline algal wackestones and packstones containing colonial and branching corals (Jones and Hunter, 1994a). The middle part is characterized by skeletal wackestones and packstones containing colonial,

branching and free living corals, along with bivalves, gastropods and rhodoliths. Foraminifera, *Halimeda*, red algae and echinoids are the dominant matrix allochems. The upper part of the Cayman Formation is similar to the middle part except that free-living corals are rare or absent and rhodoliths are less common (Jones and Hunter, 1994b). Exposures of the Cayman Formation on Grand Cayman correlate with the upper part of the Cayman Formation on Cayman Brac.

A minimum thickness of 166 m for the Cayman Formation has been obtained from subsurface data collected from Grand Cayman. Drilling terminated in the Cayman Formation before reaching the lower boundary. On Cayman Brac the Cayman Formation is estimated to be approximately 100 m thick based on the strata dipping at 0.5° to the west (Jones, 1994). The upper boundary of the Cayman Formation is a disconformity - the Cayman Unconformity (Jones and Hunter, 1994b). This unconformity developed as the result of subaerial exposure during the Messinian lowstand. Paleokarst development during this period created a highly irregular, uneven surface (Jones et al., 1984; Smith, 1987; Jones and Smith, 1988; Squair, 1988; Jones, 1994), with approximately 41 m of topographic relief (Jones and Hunter, 1994b).

The age of the Cayman Formation is difficult to determine with any certainty due to the absence of diagnostic index fossils (Jones, 1994) and $^{87}Sr/^{86}Sr$ values that have been reset by dolomitization (Pleydell *et al.*, 1990). Based on its stratigraphic relationship with the underlying and overlying formations, the Cayman Formation has been tentatively assigned a Middle Miocene age (Jones and Hunter, 1994a).

The Pedro Castle Formation is formed of dolostone, dolomitic limestone, and limestone. The type section at Pedro Castle Quarry (Jones and Hunter, 1989) on Grand Cayman is composed of rubbly weathering, relatively soft dolostone that contrasts with the very hard dolostones in the underlying Cayman Formation. The Pedro Castle Formation is approximately 2.5 m thick at the type locality. Consequently, Jones *et al.* (1994b) designated a reference section in well SH #3 that was drilled on the western peninsula of

Grand Cayman (Jones *et al.*, 1994a). Core recovered from that well includes 21.5 m of the Pedro Castle Formation and includes the upper and lower disconformable boundaries. The coral fauna in the Pedro Castle Formation is dominated by free living forms. Biotic differences between the Cayman Formation and Pedro Castle Formation reflect biofacies differences rather than systematic stratigraphic change (Jones *et al.*, 1994b; Jones, 1994). Dolostones of the Pedro Castle Formation are similar to those of the Cayman Formation in almost every other respect.

The age of the Pedro Castle Formation has been determined radiogenically due to the paucity of diagnostic index fossils. An average $^{87}Sr/^{86}Sr$ isotope ratio derived from limestones of Grand Cayman and Cayman Brac (0.70912) indicates an age of 2-5 million years, probably Lower Pliocene (Jones *et al.*, 1994b).

The disconformable upper boundary of the Pedro Castle Formation is a karsted surface. Dissolutional processes resulted in the development of an uneven surface. Deposition of the Ironshore formation took place on that uneven surface.

The Ironshore Formation (Matley, 1926) surrounds and onlaps the Bluff Group. On Grand Cayman, this Formation consists of friable, poorly consolidated reef limestones, calcarenites and oolitic limestones (Jones, 1994) that were deposited in a large lagoon - the Ironshore Lagoon (Jones and Hunter, 1990). U-Th dating of corals in the reefal limestones suggest an age of 125,000 years, which corresponds to the Late Pleistocene (Woodroffe *et al.*, 1983). These lagoonal limestones represent a shallowing upward sequence that contains a wide array of facies from subtidal lagoonal to foreshore - backshore (Jones and Hunter, 1990). Deposition of the Ironshore Formation took place during the Sangamon highstand when sea level was approximately 6 m above present day sea level. The thickness of the Ironshore Formation on Grand Cayman is variable. Deposition of the Ironshore Formation filled underlying lows and as a result the succession is thick in topographic lows and thin over topographic highs. A maximum thickness has been estimated at 17 m (Brunt *et al.*, 1973), whereas drilling on Grand Cayman has

penetrated a maximum known thickness of 21 m (Vézina, 1997).

Recent work from the northeast corner of Grand Cayman indicates that the Ironshore Formation consists of four distinct depositional sequences (Vézina, 1997; (Vézina *et al.*, in press). These sequences (Units A, B, C and D), were deposited during the last four interglacial sea level highstands and range in age from 450 Ka - 125 Ka. Unit D (125 Ka) is the most regionally extensive depositional unit in the Ironshore Formation on Grand Cayman. This unit covers most of the western part of the island.

1.6 Cayman Unconformity

The Cayman Unconformity, which separates the Cayman Formation and the overlying Pedro Castle Formation, is a sequence boundary that developed during the Late Miocene (Jones and Hunter, 1994b). Exposures of the Cayman Unconformity on Grand Cayman are rare. Where exposed, the unconformity is commonly masked by tropical weathering which renders identification difficult. Subsurface data collected from Grand Cayman indicates that it has a maximum relief of 41 m.

The lack of large scale constructional features and presence of erosional features suggests that topography developed on the Cayman Unconformity is the result of destructional processes (Jones and Hunter, 1994b). Constructional processes are of local importance in the Cayman Formation which is devoid of significant reef development. An absence of cross bedding and the presence of corals in life position precludes the development of sand ridges or dunes (Jones and Hunter, 1994b). Dissolutional fabrics are prevalent throughout the Cayman Formation. Present day karst features such as fissures, dolines and rock pinnacles are commonly associated with exposures of the Cayman Formation and the Cayman Unconformity (Matley, 1926; Doran, 1954; Rigby and Roberts, 1976; Jones *et al.*, 1984; Squair, 1988; Jones, 1994).

Topography developed on the Cayman Unconformity is the result of dissolutional processes associated with subaerial exposure (Jones and Hunter, 1994b). Paleokarst

development produced an uneven topography that was dominated by a discontinuous peripheral ridge and a centralized depression. Exposure of Grand Cayman subjected the entire island to karst processes. Karstification was not a uniform process, the depth and degree to which these processes acted displays considerable local variation. Dissolutional processes, which were more active towards the western interior of the island (Jones, 1994), produced a deep basin-like depression 20-30 m deeper than the eastern depression. The resulting topography controlled subsequent deposition. Thickness variations in the Pedro Castle Formation reflect deposition on an irregular karsted surface (Jones and Hunter, 1994b).

Karst is a surface feature limited by sea level which serves as a base level for meteoric diagenesis. The resulting topography developed on a paleolandscape depends on the initial elevation above sea level prior to subaerial exposure (Choquette and James, 1988). Exposures of the peripheral ridge attain an elevation of 10 m above present day sea level whereas the western depression is approximately 31 m bsl. Assuming that dissolution of the depression was controlled by base level, the resulting 41 m difference in elevation between the depression and the ridge marks the extent of subaerial exposure. The 41 m difference in elevation is therefore an estimate of sea level position during the lowstand (Jones and Hunter, 1994b). Sea level during the Miocene dropped by at least 41 m. This change in sea level corresponds to the eustatic Messinian lowstand (Vail *et al.*, 1977; Haq *et al.*, 1987). This eustatic lowstand due to glaciation in the southern hemisphere, persisted for 1.5 million years - the duration of the Messinian. The Cayman Unconformity presumably developed during this 1.5 million year period.

1.7 Study Area Location

Tarpon Springs Estates is an abandoned commercial development situated on the southern coast of Grand Cayman close to Breakers (Figure 1.4). The most notable feature of this area is a large water filled pit that was dredged prior to 1988. Subsequent and

continued dredging has increased the size of the pit to its current size of approximately 250 m by 50 m. This dredged pit is filled with sea water. The level of water in the pit is an expression of sea level indicating that most of the surrounding area lies approximately 0.3 m asl. Vegetation in the vicinity of this dredged pit and throughout the entire area has been removed. Secondary plant growth is currently being exploited by a herd of inquisitive cattle.

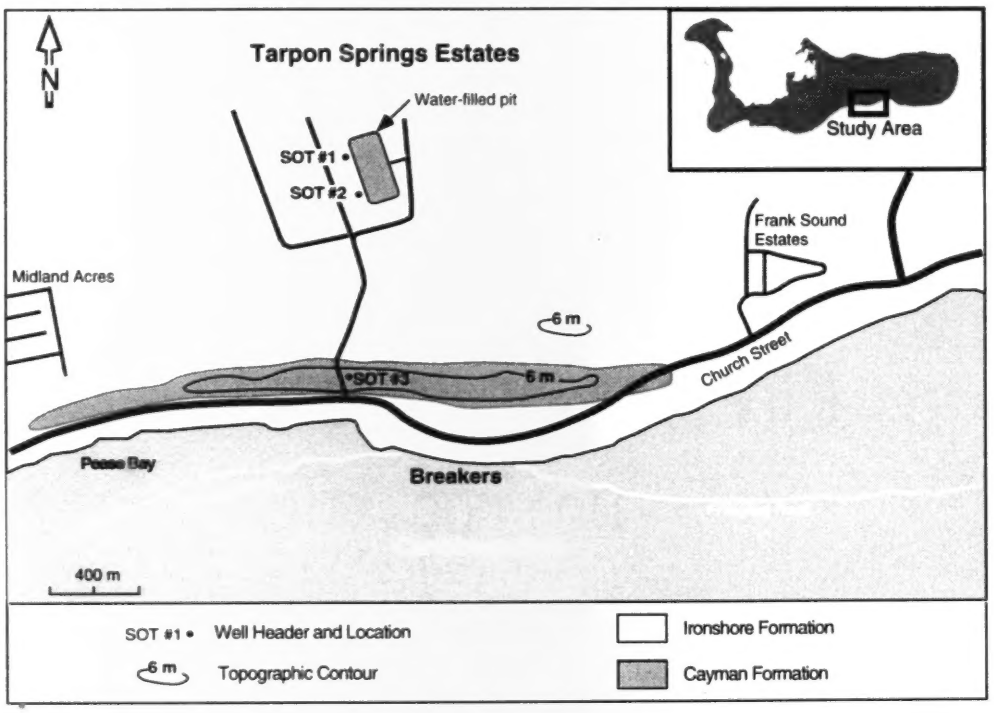

Figure 1.4: Location and surficial geology of Tarpon Springs Estates.

1.8 Methods

Core was recovered from three wells drilled at Tarpon Springs Estates (Figure 1.4). Coring was facilitated by the use of a JKS BOYLES continuous coring Winke exploration diamond drill. This system has previously penetrated depths in excess of 94 m on the island but unfavourable subsurface conditions at Tarpon Springs Estates prevented

coring past 55.8 m below sea level (bsl).

SOT #1 penetrated 42.5 m of strata whereas SOT #2 reached a depth of 55.8 m bsl, with both wells terminating in the Cayman Formation. Core recoveries for these wells averaged 80% whereas wells drilled on the western peninsula averaged 60% (Wignall, 1995). The third well (SOT#3) situated approximately 10 m asl on the peripheral ridge penetrated 17.4 m of strata with recoveries approaching 87%. Unfortunately drilling was abandoned due to mechanical failure of the equipment.

Core was boxed and shipped to Edmonton where it was cut and logged (Appendix). Petrological and scanning electron microscopy (SEM) samples were taken from the core. Forty nine thin sections were examined under transmitted light. Thin sections were stained with Alizarine Red S which differentiates calcite and aragonite from other carbonate minerals. Samples utilized for SEM analysis were fractured from the core, mounted on stubs, sputter coated with gold and examined with the Jeol JSM Field Emission Scanning Electron Microscope (FE-SEM).

Dolomitization of the Cayman Formation was predominantly fabric retentive, consequently all samples (core and thin sections) were described utilizing Dunham's classification scheme (1962) modified by Embry and Klovan (1972).

1.9 Objectives

This study investigates the sedimentology and diagenesis of the Cayman Formation at Tarpon Springs Estates. The objectives of this study are listed below.

1) Describe the sedimentology and depositional architecture of the Cayman Formation at Tarpon Springs Estates.
2) Compare these results to the leeward margin (Wignall, 1995) of Grand Cayman and to the succession described from Cayman Brac (Jones and Hunter, 1994a).
3) Describe the sedimentology of the Ironshore Formation preserved in the study area.

4) Describe and interpret the diagenetic history of the Cayman Formation in a stratigraphic context, expounding on recent work (Wignall, 1995).
5) Determine the diagenetic influence that repeated periods of subaerial exposure had on the Cayman Unconformity.
6) Determine the processes responsible for the development of topographic features evident in the Cayman Formation of the study area, thereby testing the hypothesis of Jones and Hunter (1994b), that topographic relief developed on the Cayman Formation is the result of erosional (dissolutional) processes.

Chapter 2

Stratigraphy and Sedimentology of the Cayman Formation at Tarpon Springs Estates

2.1 Stratigraphy

Surface exposures of the Bluff Group on the eastern part of Grand Cayman are primarily formed of dolostones belonging to the Cayman Formation. Dolostones of the Pedro Castle Formation are poorly preserved over this area, being restricted to topographic lows and sinkholes (Jones 1994). The Pedro Castle Formation is present in core recovered from the western part of the island (i.e., Safe Haven) and is exposed around Pedro Castle (Figure 2.1) approximately 10 m asl. The presence of the Pedro Castle Formation at various localities on Grand Cayman suggests that it was originally deposited over the entire island. The present-day restriction in the distribution of the Pedro Castle Formation is the result of subaerial erosion during the late Pliocene. Areas devoid of the Pedro Castle Formation are characterized by limestone of the Ironshore Formation or exposures of the Cayman Formation.

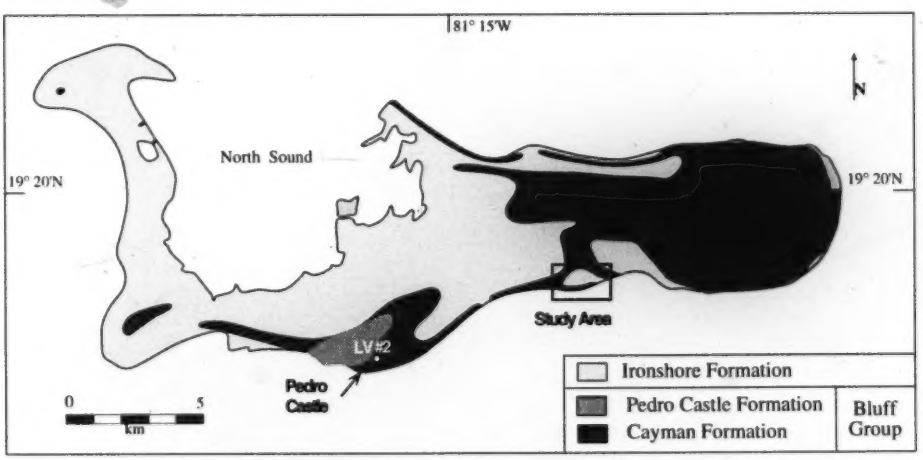

Figure 2.1: Surficial geology of Grand Cayman.

The Cayman Formation is exposed along a peripheral ridge that attains an elevation of approximately 10 m asl along the southern margin of Tarpon Springs Estates (Figure 2.2). The northern extent of this ridge is masked by dense mangrove growth that precludes detailed surface mapping. Air photo analysis, however, indicates a distinct change in vegetation from the 'dry evergreen woodland' characteristic of the Cayman Formation to the 'dry evergreen thicket' (Proctor, 1984) of the Ironshore Formation. The relationship between vegetation and lithology was also noted by Squair (1987).

The exploratory well LV#2, drilled by the Water Authority in the south-central region of the island, approximately 600 m north of Pedro Castle (Figure 2.1) terminated in the Cayman Formation at a depth of 156 m bsl. This thickness combined with the 10 m exposed in the peripheral ridge at Pedro Castle gives a total thickness of at least 166 m for the Cayman Formation. This is the maximum known thickness of the formation on Grand Cayman. At Tarpon Springs Estates, SOT #2 terminated at a depth of 56 m bsl in the Cayman Formation. This, along with the 10 m exposed in the peripheral ridge means that a total thickness of 66 m of the Cayman Formation is available for examination in the study area.

Three depositional units (Units I - III), are present in the Cayman Formation at Tarpon Springs Estates (Figure 2.6). Unit I, 6.1 m (20 ft) thick, the stratigraphically lowest unit, is composed of two facies and is only found in well SOT #2. Unit II, 34.7 m (113.8 ft) thick, encompasses three facies that can be correlated between wells SOT #1 and SOT #2. Unit III, 25.8 m (84.6 ft) thick, the uppermost unit, encompasses four facies that interfinger laterally on a meter scale. Each unit, which is bound by disconformable surfaces, contains genetically related facies that were deposited under similar conditions.

2.1.1 *Disconformity and Discontinuity surfaces*

Disconformity and discontinuity surfaces are present in the Cayman Formation. These surfaces represent periods of non-deposition and/or erosion. A disconformity is an

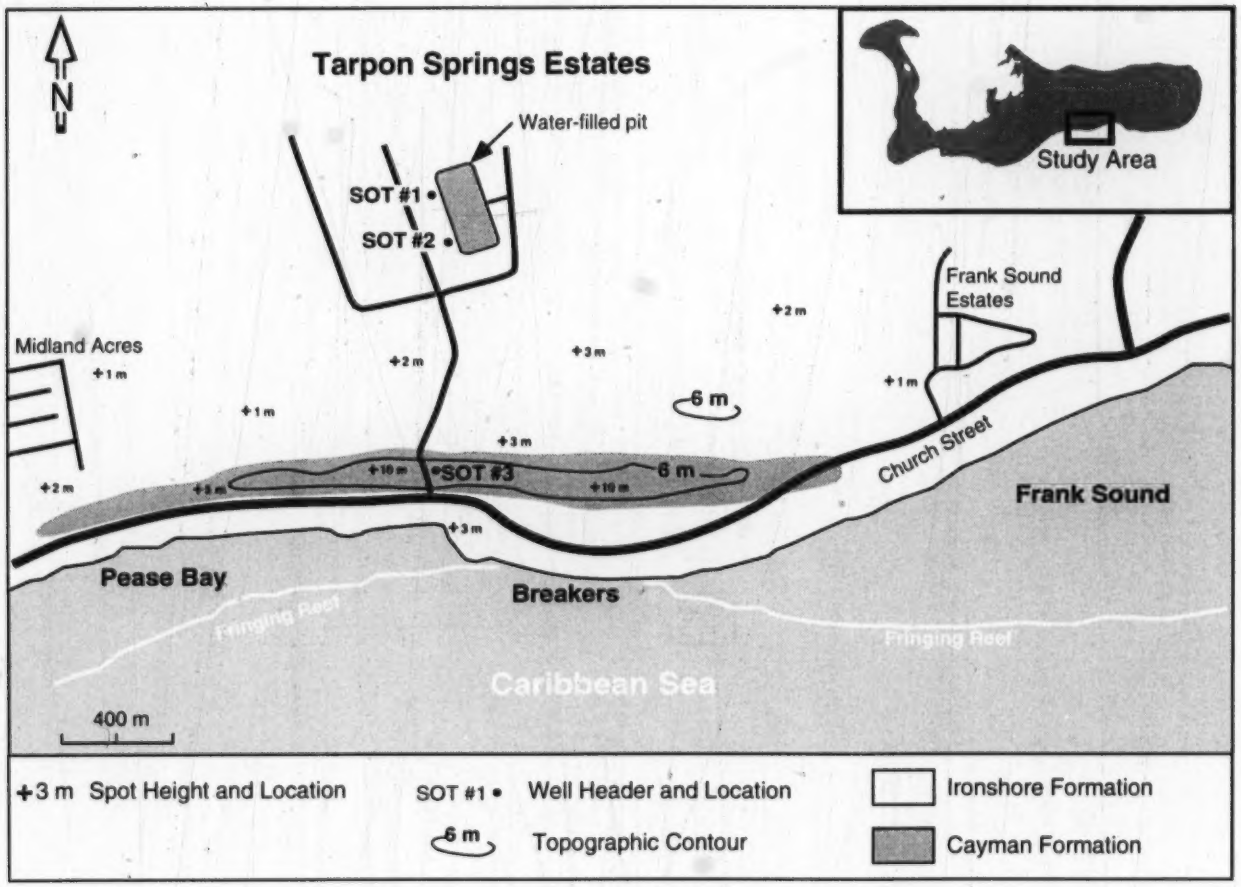

Figure 2.2 Location and surface exposure map of Tarpon Springs Estates

unconformity that may involve a period of large scale erosion. Discontinuity surfaces are intraformational breaks in sedimentation that do not involve large scale erosion (Bromley, 1975). These surfaces, represented by marine hardground surfaces in the study area, are lower in rank than an unconformity. Depositional Unit I is separated from Unit II by a marine hardground surface developed in SOT #2 at a depth of 49.6 m (162.8 ft). Unit II is separated from Unit III by a hardground surface in SOT #2 at a depth of 14.9 m (48.8 ft). These discontinuity surfaces, irregular in nature, form sharp contacts between the facies above and below. Development of the irregular surface has produced overhanging ledges. Cavities developed below the hardground are filled with geopetal sediment that is lithologically the same as that of the overlying facies.

The upper bounding surface of Unit II (14.9 m bsl in SOT #2) is encrusted by a layer of coralline red algae. Borings are present in the rocks below the hardground surface (Figure 2.3) (George Pemberton, pers. com.). Most borings are solution enlarged and filled with a coarsely crystalline sediment. Colonization of the hardground surface

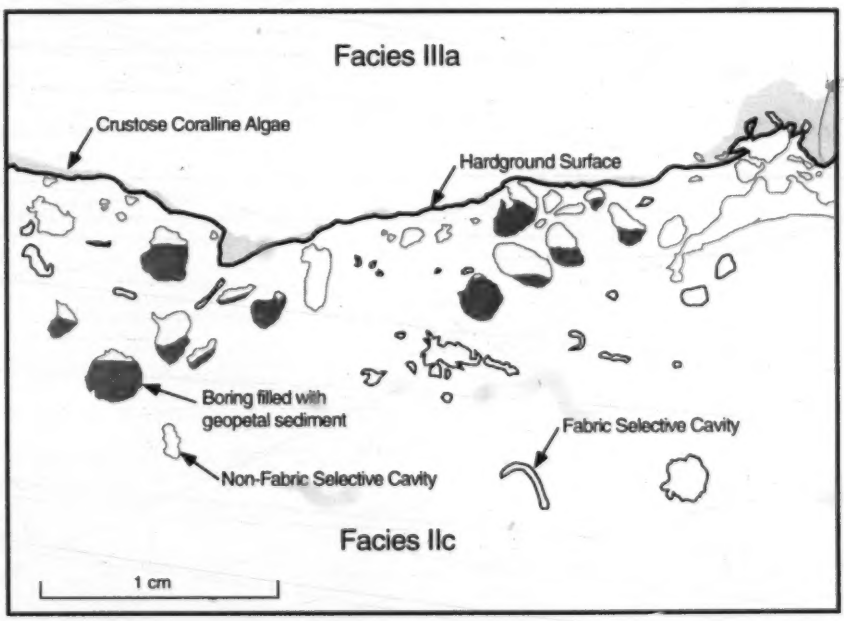

Figure 2.3: Hardground developed in SOT #2 at 14.9 m bsl (48 ft) separating units II and III. Drawn from thin section.

by encrusting coralline algae and boring organisms indicates a period of non-deposition - sediment accumulation would have buried the surface and prevented colonization.

The Cayman Formation is separated from the overlying Pleistocene Ironshore Formation by a disconformable surface. This sequence boundary is a composite unconformity that probably formed during two periods of subaerial exposure. The first period of erosion, associated with the Messinian lowstand (Jones and Hunter, 1994b), produced a karsted surface on the Cayman Formation which has been termed the Cayman Unconformity (Jones and Hunter, 1994b). A second period of subaerial exposure, during the late Pliocene, removed the Pedro Castle Formation at Tarpon Springs Estates and exposed the Cayman Formation to additional near surface erosion and diagenetic processes.

2.2 Sedimentology of the Cayman Formation

Dolostones in the Cayman Formation at Tarpon Springs Estates have commonly preserved the fabric(s) and texture(s) of the original limestone. Following Rezak and Lavoie (1990), fabric is herein defined as: 1) grain to grain relationships (orientation, shape, size and nature of grain to grain contacts), 2) grain to matrix relationships (grain supported versus matrix supported), and 3) matrix component particle relationships (orientation, shape, size and nature of particle to particle contacts). Texture refers to the particle size distribution in the sediment and is therefore a component of the fabric.

Skeletal allochems such as foraminifera, coralline red algae, and echinoderm fragments have commonly been replaced by fabric-retentive dolomite. Corals, bivalves, and gastropods are commonly leached and/or preserved as molds. These larger skeletal allochems possess distinguishable 'shapes' and as such can be identified (in some cases to the species level) on the basis of their molds.

The fabric-retentive dolostones of the Cayman Formation are classified and

described using Embry and Klovan's (1971) modifications to Dunham's (1962) classification scheme. Following the lead of Jones and Hunter (1994b) and Wignall (1995), matrix allochems (< 2 mm) and component allochems (> 2 mm) are described separately. Allochems have been affected by dissolution and dolomitization. These diagenetic processes render identification difficult, obscuring the depositional fabric. Diagenetic alteration therefore limits facies comparisons and paleoenvironmental interpretations (Wignall, 1995).

2.2.1 *Biota*

Corals and large bivalves are the most apparent and easily recognizable biota in the Cayman Formation at Tarpon Springs Estates (Figure 2.4). Corals, which are volumetrically the dominant skeletal component, exhibit high species diversity. Hunter (1994) delineated seven coral associations in the Bluff Group on Grand Cayman according to recurring sets of species. Of these, the *Stylophora*, *Stylophora-Porites*, *Montastrea limbata*, and the Free Living Coral association are found in the Cayman Formation at Tarpon Springs Estates (Figure 2.5). Strata of the Cayman Formation are dominated by the *Stylophora* Association. This association grades into the *Stylophora-Porites* association where *Porites* co-dominates the coral fauna. Coral associations in the study area are laterally continuous or pass laterally into each other (Figure 2.5). The coral associations in the study area (Table 1), have a lower species diversity than those described by Hunter (1994). This is primarily a reflection of the fact that Hunter (1994) based his descriptions on numerous localities across Grand Cayman whereas species diversity in the study area is based on analysis of the recovered core.

In contrast to the volumetrically dominant coral fragments, foraminifera and coralline red algae are the numerically dominant faunal elements in the Cayman Formation in the study area (Figure 2.4). Foraminifera are dominated by rotaliids, the most notable being *Amphistegina* along with lesser numbers of *Sphaerogypsina,*

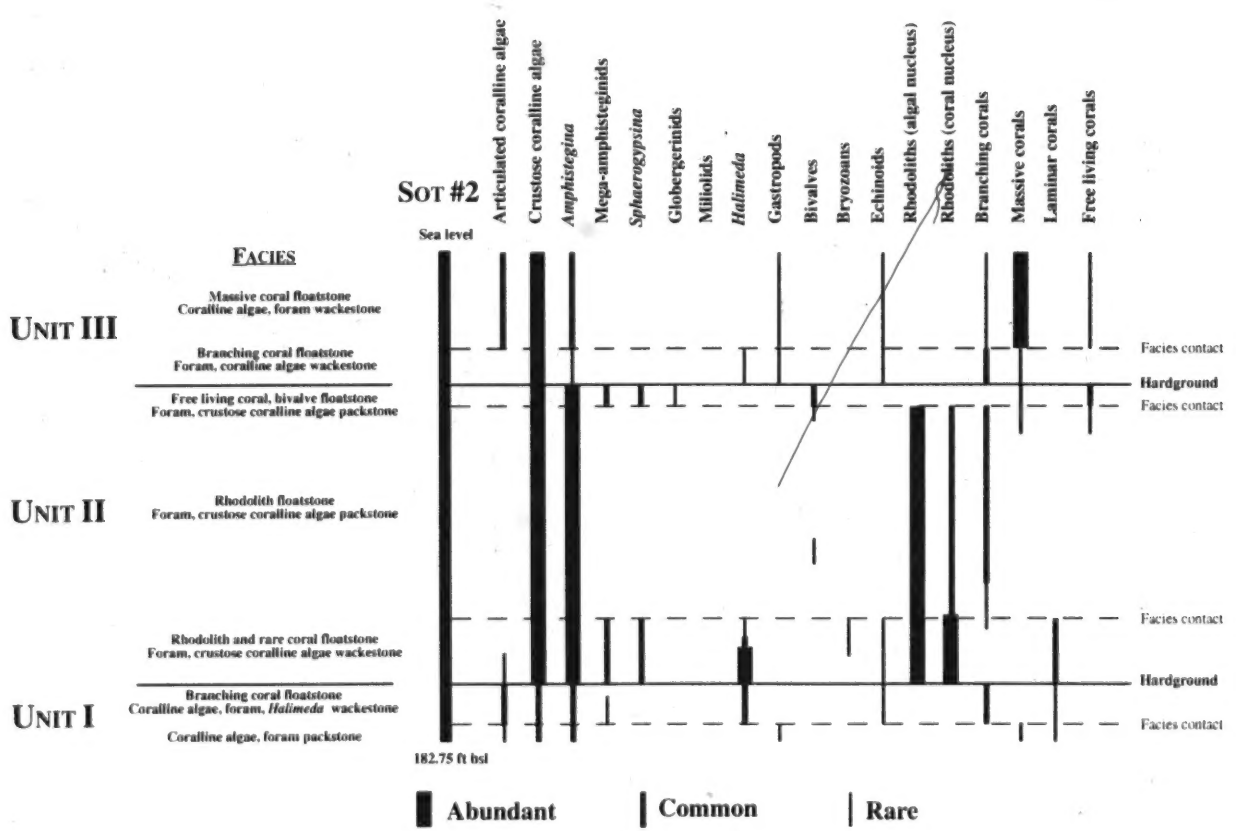

Figure 2.4: Faunal distribution in the Cayman Formation of well SOT #2

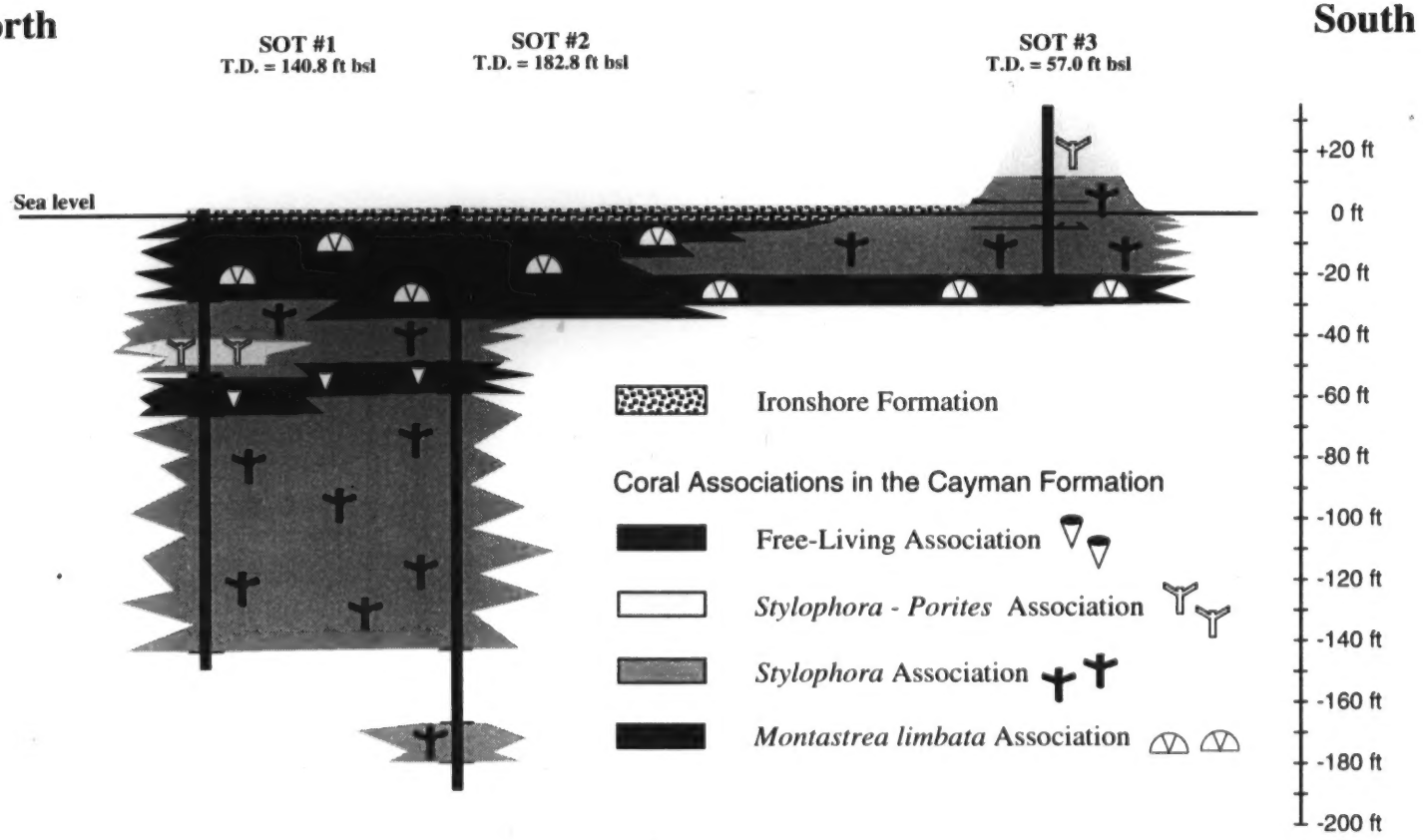

Figure 2.5: Distribution of coral associations in the Cayman Formation at Tarpon Springs Estates

Coral Association / Species	*Stylophora*	*Stylophora-Porites*	*Montastrea limbata*	Free living coral
Stephanocoenia duncani			R	
Stylophora spp.	C	C	R	R
Agaricia cf. *agaricites*	R		R	
Agaricia cf. *fragilis*	R		R	
Leptoseris n. sp. A			R	R
Siderastrea sp.			R	
Porites sp. 1 (massive)	R		R	R
Porites barcoaensis	LC	C	R	
Favia sp. 1	R		R	
Favia sp. 2			R	
Favia sp. 3	R	VR	VR	
Diploria strigosa	R		R	
Diploria cf. *labyrinthoformis*	R		R	
Teleiophyllia grandis			VR	R
Colpophyllia n. sp. A				R
Montastrea limbata	R	LC-R	C	R
Montastrea endothecata	R		R	
Montastrea sp. 3			R	
Trachyphyllia bilobata			VR	R
Trachyphyllia n. sp. B			VR	R
Dichocoenia sp.			R	
Diversity	**11**	**4**	**20**	**8**

Table 1: Coral associations in the Cayman Formation described by Hunter (1993). Species identified at Tarpon Springs Estates are shaded. C=common, LC=locally common, R=rare, VR=very rare.

mega-amphisteginids, and globigerinids. Coralline red algae is present as variable sized fragments in the matrix or encrusting immobile (in situ corals) and mobile (coral fragments, lithoclasts and algal fragments) substrates. The latter forms rhodoliths (Ginsburg and Bosselini, 1973) which are a common component of the Cayman Formation in the study area. In addition, *Halimeda* and echinoid fragments are present in variable amounts whereas bryozoan fragments are rare.

2.2.2 *Facies in the Cayman Formation at Tarpon Springs Estates*

Nine facies, all formed of dense, white, finely crystalline dolostone, are present in the study area (Table 2).

FACIES I a

Coralline algae and *Amphistegina* packstone/wackestone facies

This facies is characterized by numerous coralline red algae fragments and *Amphistegina*. The latter are commonly leached and poorly preserved. Coral fragments, if present, include laminar (*Leptoseris*?) forms that are commonly less than 1 cm long. Allochem abundance is variable in this facies with areas of packstone and wackestone being present locally.

FACIES I b

Branching coral, coralline algae, *Amphistegina*, floatstones/wackestone facies

Fragments of *Stylophora* spp. and *Porites barcoaensis* are the dominant allochems in the floatstones. The matrix consists of fragmented crustose and articulated coralline-algae, *Amphistegina*, and *Halimeda* wackestones with rare echinoid fragments. *Porites* and *Halimeda* abundance is variable on a local scale.

FACIES II a

Rhodolith, foraminifera, crustose coralline algae, floatstone/packstone facies

Rhodoliths are the dominant component in this facies. These spherical or prolate coralline algal nodules are 3 mm to 2 cm long. Rhodolith size and shape is directly

FACIES	FACIES DESCRIPTION	COMPONENT ALLOCHEMS	MATRIX ALLOCHEMS	DOMINANT ALLOCHEMS	RARE ALLOCHEMS	PRIMARY SEDIMENTARY STRUCTURES	TRACE FOSSILS / BORINGS
I a	Coralline algae, *Amphistegina* Packstone	Rare laminar and massive corals	Coralline algae, *Amphistegina*	Coralline algae, *Amphistegina*	Gastropods	Not apparent	Not apparent
I b	Branching coral, coralline algae, *Amphistegina, Halimeda* Floatstone/Wackestone	*Stylophora* spp. *Porites barcoaensis*	Coralline algae *Amphistegina Halimeda*	*Stylophora* spp. Coralline algae *Amphistegina*	Echinoid frags.	Rare laminations	*Entobia*
II a	Rhodolith, foraminifera, crustose coralline algae, laminar coral Floatstone/Packstone	Rhodoliths *Leptoseris* ?	Foraminifera Crust. coralline algae *Halimeda*	Rhodoliths *Amphistegina* Crust. coralline algae	Echinoid frags. Bryozoan frags. Miliolid forams	Not apparent	Not apparent
II b	Rhodolith, foraminifera, crustose coralline algae, branching coral Floatstone/Packstone	Rhodoliths *Stylophora* spp. *Porites barcoaensis* Mollusc fragments	*Amphistegina* Crust. coralline algae *Sphaerogypsina* Mega-amphisteginids	Rhodoliths *Amphistegina* Crust. coralline algae Mollusc fragments	*Halimeda* Echinoid frags. Bryozoan frags. Miliolid forams	Not apparent	*Entobia* Worm borings
II c	Free living coral, bivalve, foraminifera, coralline algae Floatstone/Packstone	Free living corals Bivalve fragments *Montastrea*	*Amphistegina* Coralline algae *Sphaerogypsina* Mega-amphisteginids	*Amphistegina* Free living corals Coralline algae Bivalve fragments	*Halimeda* Echinoid frags. Gastropod frags. Globigerinid forams	Not apparent	Worm borings

Table 2: Facies of the Cayman Formation at Tarpon Springs Estates.

FACIES	FACIES DESCRIPTION	COMPONENT ALLOCHEMS	MATRIX ALLOCHEMS	DOMINANT ALLOCHEMS	RARE ALLOCHEMS	PRIMARY SEDIMENTARY STRUCTURES	TRACE FOSSILS / BORINGS
III a	Branching coral, *Halimeda*, coralline algae, mollusc Floatstone/Wack-Packstone	*Stylophora* spp. *Porites barcoaensis* *Montastrea*	*Halimeda* Coralline algae, Mollusc frags.	*Stylophora* spp. *Porites barcoaensis* *Halimeda* Coralline algae	Foraminifera	Not apparent	*Entobia*
III b	Massive coral, coralline algae, *Amphistegina* Floatstone/Wackestone	*Montastrea limbata* Free living corals Gastropods Bivalve frags.	Coralline algae *Amphistegina* Mollusc frags.	*Montastrea limbata* Coralline algae *Amphistegina* Mollusc frags.	*Porites* sp. (massive) *Halimeda* Echinoid frags. *Porites barcoaensis*	Not apparent	Worm borings *Entobia* *Lithophaga* Rhizoliths
III c	Branching coral, coralline algae, *Amphistegina, Halimeda* Floatstone/Wackestone	*Stylophora* spp. *Porites barcoaensis*	Coralline algae *Amphistegina* *Halimeda*	*Stylophora* spp. Coralline algae *Amphistegina* *Halimeda*	Echinoid frags. *Porites* sp. (massive)	Not apparent	*Entobia* Worm borings
III d	Branching coral, rare massive coral, foraminifera, coralline algae Floatstone/Packstone	*Porites barcoaensis* *Stylophora* spp. *Porites* sp. (massive)	*Amphistegina* Coralline algae Mega-amphisteginids *Sphaerogypsina*	*Porites barcoaensis* *Stylophora* spp. *Amphistegina* Coralline algae	Globigerinid forams Mollusc frags. *Halimeda* Echinoid frags.	Not apparent	*Entobia* Worm borings Mollusc borings Rhizoliths

Table 2 (cont'd): Facies of the Cayman Formation at Tarpon Springs Estates.

related to the size and shape of the nuclei. Rhodoliths that developed on branching coral fragments are commonly prolate due to the nature of the coral fragment. Spherical rhodoliths commonly nucleated on coralline algae fragments. Rhodoliths are differentiated from algal encrusted coral fragments because the latter are incompletely enveloped by algae. The laminar coral fragments, dominated by *Leptoseris*, are small (< 2 cm) and encrusted by coralline algae. Most of these coral fragments served as nuclei for rhodoliths. The packstone matrix contains numerous *Amphistegina*, mega-amphisteginids, *Sphaerogypsina*, and fragmented crustose coralline algae and locally, articulated coralline algae. Articulated coralline algal fragments are small (0.2 - 0.8 mm) and abraded. *Halimeda* is a relatively common matrix allochem whereas echinoid fragments, bryozoan fragments, globigerinid and miliolid forams are rare.

FACIES II b

Rhodolith, foraminifera, crustose coralline algae, and fragmented branching coral floatstone/packstone facies

Rhodoliths, which dominate this facies, are large (> 1 cm) and primarily nucleated on coralline algal fragments. The coral fauna is represented by branching forms (*Stylophora* spp., *Porites barcoaensis*) that are bored by sponges, worms, and/or molluscs and encrusted by coralline algae to varying degrees. Mollusc fragments (bivalves and gastropods) are locally abundant.

Rhodoliths, encrusted corals, and mollusc fragments are embedded in a packstone matrix that is dominated by foraminifera and coralline algal fragments. The foraminifera fauna is dominanted by *Amphistegina*, with lesser numbers of *Sphaerogypsina*, mega-amphisteginids, and rare miliolids. *Halimeda* is present in variable numbers whereas echinoid and bryozoan fragments are rare.

FACIES II c

Free living coral, bivalve, foraminifera, coralline algae floatstone/packstone facies

Free-living corals with scattered massive corals and bivalve fragments dominate the greater than 2 mm size component of this facies. Coral abundance is locally variable. The coral fauna is representative of the Free-living Coral Association as described by Hunter (1994). The corals and bivalves are held in a packstone matrix that is dominated by foraminifera, including *Amphistegina* with fewer *Sphaerogypsina*, mega-amphisteginids and rare globigerinids. Fragmented coralline red algae (crustose and articulated) is a common matrix component whereas *Halimeda* is locally abundant. Fragmented echinoids, gastropods, and bryozoans are rare in this facies.

FACIES III a

Branching coral, *Halimeda*, coralline red algae and mollusc floatstone/packstone-wackestone facies

This facies is characterized by a coral fauna that is dominated by *Stylophora* spp., locally abundant *Porites barcoaensis*, and scattered fragments of *Montastrea*. This coral fauna corresponds to the *Stylophora* or the *Stylophora-Porites* association of Hunter (1994) where *Porites* is locally abundant. Most corals in this facies are not in growth position. Many of these coral fragments are enveloped by a diagenetic (reactivation) rim of fine grained calcite (*cf.* Wignall, 1995). The packstone to wackestone matrix around the coral fragments contains *Halimeda*, fragmented coralline algae, and molluscs. Foraminifera are rare in this facies.

FACIES III b

Massive coral, fragmented coralline red algae and *Amphistegina* floatstone/ wackestone facies

This facies consists of massive corals (e.g., *Montastrea limbata*), coralline red algae, rare free living corals, gastropods, and disarticulated bivalves. The high diversity coral fauna in this facies includes *Diploria*, *Porites* (massive), *Porites barcoaensis*, and

Stylophora spp.. This suite of corals is characteristic of the *Montastrea limbata* coral association (*cf.* Hunter, 1994). The presence of geopetal sediment in coral molds, position of corallites and the orientation of rare branching forms indicate that corals have been transported. Corals are commonly enveloped by rims of micrite (reactivation rims). These coral fragments form floatstones and local lenses of rudstone. The wackestone matrix is composed primarily of fragmented coralline red algae and *Amphistegina* with rare mollusc fragments, *Halimeda*, and echinoid spines.

FACIES III c

Branching coral, coralline algae, *Amphistegina* and variable *Halimeda* floatstone/ wackestone-packstone facies

The variable wackestone and packstone matrix of this facies varies in mud content and in biotic abundance. *Amphistegina* and fragmented coralline algae are dominant allochems in the matrix whereas *Halimeda* varies throughout this facies. This facies is similar to Facies Ib with *Stylophora*, *Porites* fragments and coralline algae as common skeletal components. This facies differs from Facies Ib due to the presence of scattered massive corals and mollusc fragments in the latter.

FACIES III d

Branching and rare massive coral, foraminifera, and coralline algae floatstone/ packstone facies

Branching and massive corals consisting primarily of *Porites barcoaensis, Stylophora* spp.,. and *Porites* sp. (massive) are the major components in these floatstones. Most corals in this facies have been bored by sponges, worms and/or molluscs. Foraminifera, predominantly *Amphistegina*, with lesser numbers of mega-amphisteginids, rare *Sphaerogypsina*, and globergerinids, combined with fragmented coralline algae to form the packstone matrix. The matrix also contains rare mollusc fragments, ostracode shells, *Halimeda,* and echinoid spines.

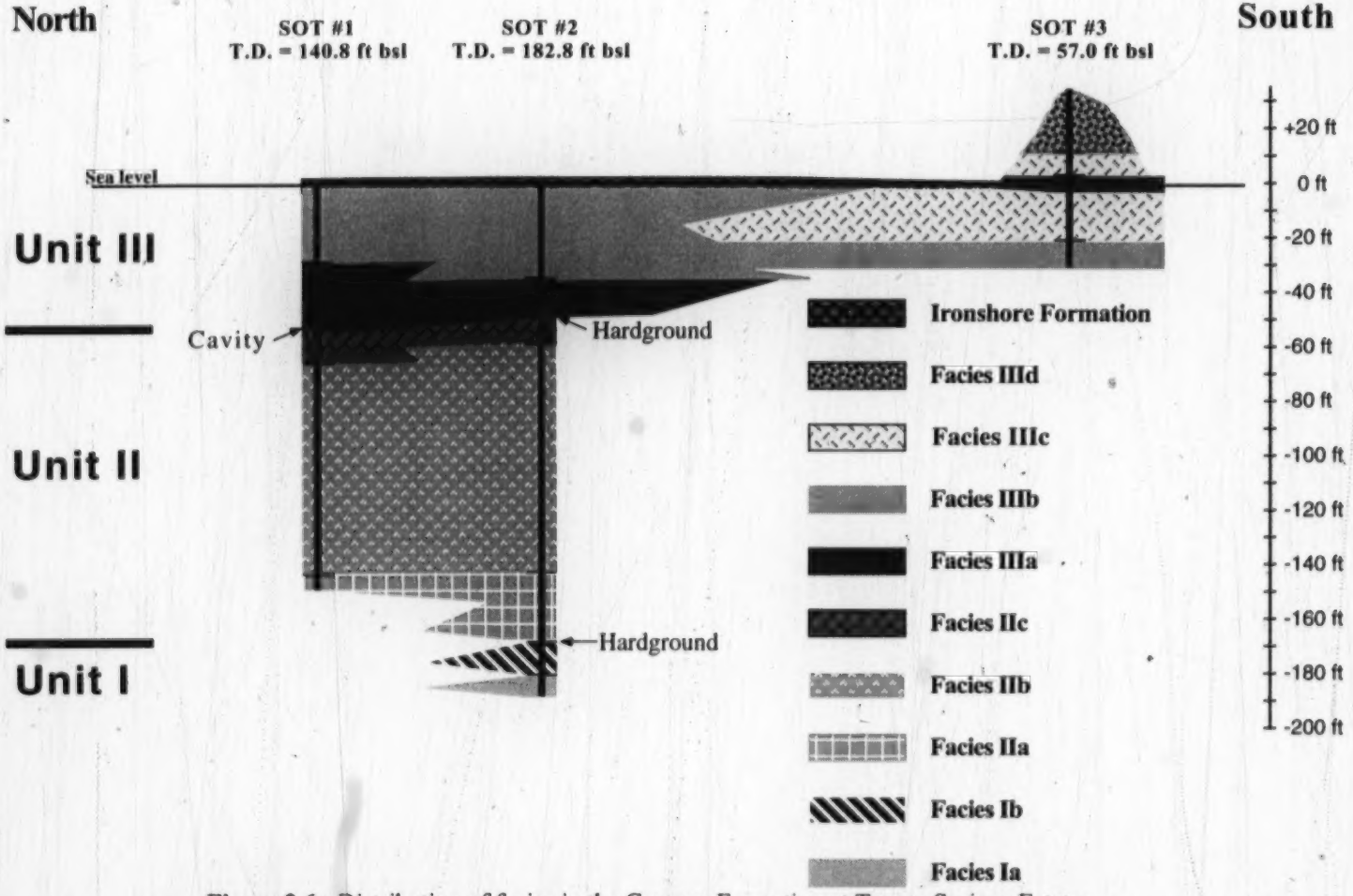

Figure 2.6: Distribution of facies in the Cayman Formation at Tarpon Springs Estates.

2.2.3 *Facies Architecture*

Facies in the Cayman Formation at Tarpon Springs are grouped into three depositional units (Figure 2.6). Unit I is composed of Facies Ia and Facies Ib. The contact between Facies Ia and the overlying, Facies Ib is gradational. This transition is marked by the appearance of branching coral fragments and a decrease in allochem abundance (change from a predominantly packstone matrix to a wackestone matrix). The vertical and lateral variability of these facies are unknown because Unit I is only known from SOT #2. The contact between Facies Ib and Facies IIa is marked by a marine hardground.

Unit II is composed of Facies IIa, IIb, and IIc (Figure 2.6). Facies of Unit II are laterally continuous between wells SOT #1 and SOT #2. Facies IIa, grades vertically into Facies IIb. This change is marked by a decrease in the abundance of laminar coral fragments and rhodoliths. Although rhodoliths decrease in abundance, their diameter increases relative to those of Facies IIa. Overlying the rhodolith floatstones of Facies IIb are the fragmented free living coral and bivalve floatstones of Facies IIc. A marine hardground surface (in SOT #2) marks the sharp boundary between units I and II.

Unit III contains four facies which display the highest degree of variability relative to the other units (Figure 2.6). The lowermost facies, Facies IIIa, is present in all of the wells in the study area. This facies is laterally continuous between SOT #1 and SOT #2 whereas it occurs stratigraphically higher in SOT #3. Facies IIIb is laterally continuous between all of the wells in the study area. Facies IIIc, present in SOT #3, laterally interfingers on a meter scale with Facies IIIb. Facies IIId, described from SOT #3, is positioned stratigraphically above SOT #1 and SOT #2.

The distribution of coral associations in the study area displays similar variability to the distribution of facies (Figures 2.5 and 2.6). Coral associations commonly grade vertically into one another whereas abrupt changes are separated by disconformity surfaces. The lateral variability of the *Stylophora* Association in Facies Ib (Unit I) is

unknown due to its limited occurrence (SOT # 2). Coral associations in Unit II are laterally continuous between SOT #1 and SOT #2. The *Stylophora* Association in Facies IIb vertically grades into the Free-living coral Association in Facies IIc whereas the transition between coral associations in units II and III (Facies IIc and Facies IIIa) is abrupt. Coral associations in Unit III are variable. The *Stylophora* Association in Facies IIIa grades into the *Stylophora-Porites* Association where *Porites* co-dominates the coral fauna. The *Montastrea limbata* association of Facies IIIb laterally interfingers with the *Stylophora* Association of Facies IIIc.

Chapter 3

Depositional Environment and Architecture of the Cayman Formation at Tarpon Springs Estates

3.1 Introduction

Sediment accumulation on carbonate banks is controlled by factors such as water depth, salinity, temperature, water energy, turbidity, and cross-bank currents (Jones and Desrochers, 1992). These factors are dictated, to a large extent, by the morphology of the bank margin. A segmented to continuous rampart of reefs or shoals developed along the bank margin absorbs and dissipates water energy and controls water exchange between the open ocean and the bank (James and Kendall, 1992). Development of a rimmed margin generates a variety of protected, low energy environments on the bank. These environments are characterized by mud-rich lithofacies. A rimmed margin restricts water circulation and precludes off-bank transport of sediment. Sediment accumulation is controlled by water depth and accomodation space.

Carbonate banks that lack a rimmed margin are swept by cross bank currents and/or waves. As a result, these banks are characterized by high energy levels and sand-rich lithofacies with localized patch reefs and sand shoals (Jones and Desrochers, 1992). Water circulation in these environments is not restricted and sediment is commonly transported off-bank into deeper water. Sediment accumulation is controlled by the depth of wave abrasion, water depth, and accomodation space (James and Kendall, 1992).

Grand Cayman is an exposed pinnacle of the Cayman Ridge. There is no evidence that this isolated carbonate island was ever connected to a continental landmass during the Tertiary. Deposition during the Miocene took place on an isolated carbonate bank (when completely flooded) or around an isolated island (when not completely flooded). The Cayman Formation preserved in the study area records deposition that took place on

an isolated bank.

Tarpon Springs Estates is a low lying area except for a ridge along the southern margin that attains a maximum elevation of 10.7 m (35 ft). This narrow ridge (20 m wide) is part of the peripheral ridge that parallels the southern windward coast of Grand Cayman (Jones and Hunter, 1994b). The location, shape, trend and nature of the ridge are consistent with that expected of a constructional feature such as a reef or series of sand shoals. Examination of the ridge and analysis of core and samples collected from the ridge, however, failed to show any evidence of constructional features. Corals are scattered throughout the rocks that form the ridge in the study area (SOT #3). These corals are commonly fragmented and abraded and do not represent *in situ* coral frameworks. By comparison, modern fringing reefs around Grand Cayman consist of ridge-like piles of coral rubble and sand that are formed by the transport and deposition of sediment by hurricanes and represent physically constructed features (Blanchon, 1995). Fragmented and abraded corals in the Tarpon Springs area indicate transport; however, most fragments are matrix supported and are not representative of the densely packed storm derived rubble found in the modern fringing reefs around Grand Cayman. The absence of constructional features coupled with evidence of karst erosion led Jones and Hunter (1994b) to suggest that the peripheral ridge was formed by destructional processes during the Messinian lowstand. The peripheral ridge is therefore a post-depositional feature, not a constructional feature that would have modified environmental conditions during deposition of the Cayman Formation. Nevertheless, during deposition of the Cayman Formation there is a possibility that a rimmed margin may have existed offshore from the present-day coastline - in an area since lost to erosion (Jones and Hunter, 1994b).

Facies in well SOT #3, drilled on the ridge at Tarpon Springs Estates, can be correlated with more inland areas (wells SOT #1 and SOT #2). These facies are indicative of deposition in a moderately high energy, open bank setting. As such there is

no indication of a rimmed margin that would have influenced deposition in the study area. Accordingly, deposition of carbonates that now form the Cayman Formation, probably took place on an open bank that was swept by cross-bank currents. Deposition in this environment was primarily controlled by water depth and water energy.

3.2 Water Depth

The sediments that now form the Cayman Formation at Tarpon Springs Estates accumulated in open water on a shallow bank. Abundant calcareous algae (Codiaceae and Corallinaceae) and hermatypic corals indicates deposition in the photic zone.

Coralline algae is a common skeletal component in modern Caribbean carbonate environments, ranging from sea-level to depths of 290 m (Littler *et al.*, 1991). Coralline algae is common in the Cayman Formation at Tarpon Springs Estates, dominated by *Lithoporella* with lesser amounts of *Neogoniolithon* (Hills, pers. com.). The former prefers water depths of 20 - 70 m (Minnery *et al.*, 1985) in the Gulf of Mexico whereas *Neogoniolithon* (Adey *et al.*, 1982) commonly resides between the intertidal to depths of 30 m in the Caribbean (Figure 3.1).

Rhodoliths have been found in water depths of 25 - 130 m from the Caribbean Sea and Gulf of Mexico (Montagioni, 1979; Minnery, 1990; Reid and Macintyre, 1988). Modern rhodoliths are currently forming under high energy conditions in water 0 - 2 m deep around Grand Cayman. Comparison of rhodoliths in the Cayman Formation with modern rhodoliths of Grand Cayman indicates that they may have formed in water less than 10 m deep.

Codiacean algae, represented by *Halimeda* in the study area, has been described from subtidal to water depths in excess of 140 m (Hillis-Colinvaux, 1986). *Halimeda* appears to be more tolerant to greater water depths relative to coralline algae and corals in the study area (Figure 3.1). This form of codiacean algae is therefore not as useful for constraining water depths in the photic zone relative to coralline algae and corals.

Corals have been used as bathymeters (Wells, 1967). Although there is no distinct lower bathymetric limit to reef corals, they are a common component in tropical waters from intertidal to depths of approximately 50 m. Below that depth there is a marked decrease in the number of species because of the significant decrease in light levels (Wells, 1967). The coral fauna in the Cayman Formation is, however, similar to the *Diploria - Montastrea - Porites* assemblage described from modern Caribbean banks that are covered by water less than 45 m deep (Rezak, 1977; Jones and Hunter, 1994b).

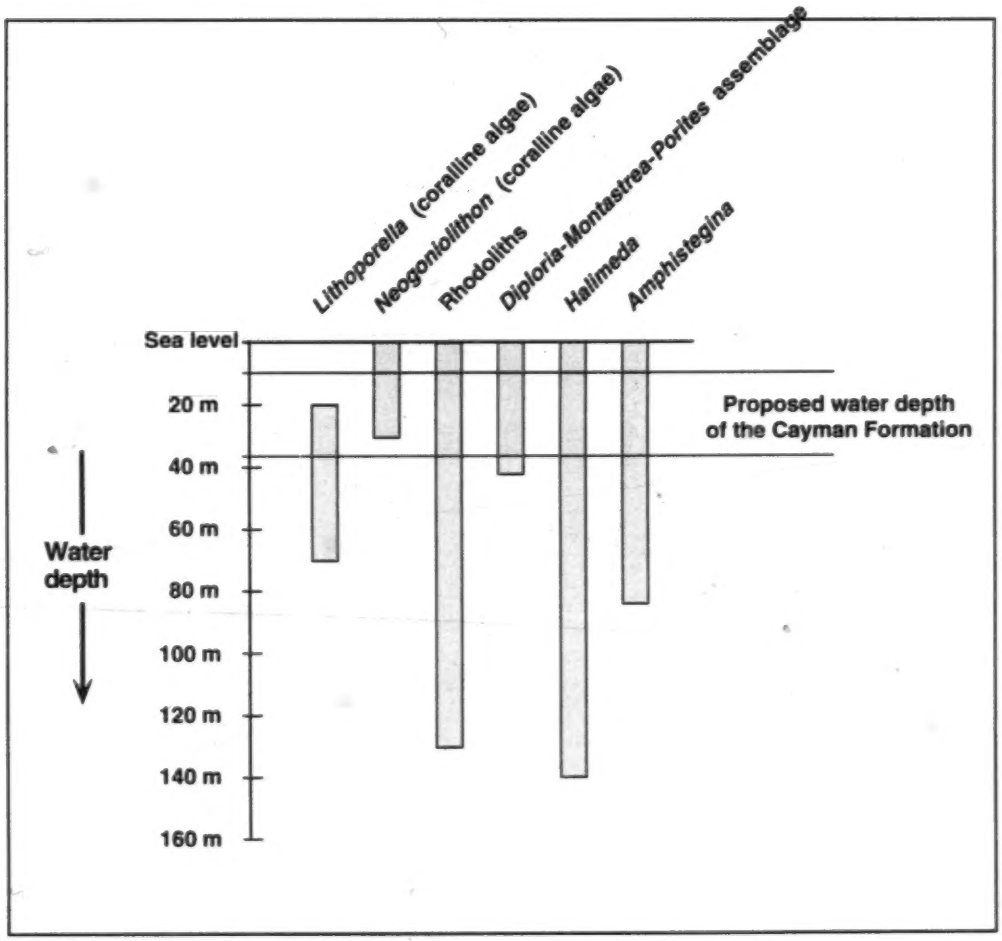

Figure 3.1: Depth distribution of biota and proposed water depth during deposition of the Cayman Formation at Tarpon Springs Estates.

Modern coral reefs exhibit a depth zonation due to decreasing water energy and light intensity with increasing depth (James and Bourque, 1992). Laminar and branching corals are delicate and favour deep, low energy conditions relative to robust massive corals. Coral distibution in the Cayman Formation on Cayman Brac is not a function of water depth and energy but appears to have been controlled by substrate conditions (Jones and Hunter, 1994b). Substrate conditions also appear to be the controlling factor for coral distribution in the Tarpon Springs area. Branching corals are commonly found in wackestone matrices whereas massive corals are common in packstone matrices. Branching corals have polyps elevated above the substrate and have a decreased surface area relative to massive corals. These features allow branching corals to reside in muddier substrates relative to massive corals. The deposition of fine grained sediment may be further perpetuated due to the baffling ability of the branching corals (Jones and Hunter, 1994b).

Amphistegina is a common component of the Cayman Formation in the study area. This rotaliid foraminifera, containing algal symbionts, is also a common component in modern banks and has been found in water 5 - 84 m deep from Saba Bank (Hofker, 1980), 1 - 47 m in the West Indies (Radford, 1976), and 5-35 m in the French Polynesian Islands (Vénec-Peyré, 1991).

The coarse grained nature of the sediment helps to further constrain water depth. Coral fragments and most rhodoliths are of cobble size and contribute to the coarse grained nature of the sediment. Most of these allochems display evidence of transportation suggesting high energy conditions in shallow water. Precise water depths are difficult to determine for the Cayman Formation (Jones and Hunter, 1994b). The coarse grain size, presence of a diverse photosynthetic biota, and apparent lack of mud in the Cayman Formation are consistent with deposition above storm wave base in water 10 - 35 m deep (Figure 3.1). Depositional units (units I - III) in the study area were probably deposited in water 10 - 35 m deep. Each unit was deposited at different water

depths (and energy) relative to one another in this 10 - 35 m depth interval.

3.3 Water Energy

Miocene deposition of the Cayman Formation at Tarpon Springs Estates took place under moderate to high energy conditions on an open bank. Corals and bivalves in the study area are commonly fragmented and display evidence of abrasion. Sediment grain size encompasses cobble to mud sized sediment but is dominated by sand to pebble sized sediment.

Energy levels varied temporally and spatially throughout the depositional history of the Cayman Formation in the study area. Unit I and Unit III contain coral fragments that are held in wackestone and packstone matrices. Micrite is common in units I and III but less abundant in Unit II. A lack of *in situ* organisms capable of baffling sediment indicates that micrite was deposited in low energy conditions. The abundance of micrite in units I and III suggests that these units accumulated under lower energy conditions relative to Unit II.

Unit II consists of floatstones and rare rudstones characterized by coarse grain sizes and a grain supported (packstone) matrix. Unit II was deposited under higher energy conditions in shallower water relative to Unit I and III. Skeletal allochems in Unit II exhibit a higher degree of physical breakage (an increase in fragment abundance accompanied by a decrease in fragment size) and abrasion relative to the other units.

Articulated coralline algae are common in Unit I and Unit III. These forms are more delicate than the crustose varieties, tending to inhabit less energetic waters (Scoffin, 1987). Articulated coralline algae is rare in Unit II which is dominated by crustose forms (*Lithoporella)*.

Additional evidence for the existence of higher energy, shallower water conditions in Unit II is provided by the abundance of spherical shaped, laminar rhodoliths. Rhodolith shape and growth form has been attributed to the energy of the depositional

environment (Bosselini and Ginsburg, 1971). Spheroidal nodules form in response to frequent repositioning by waves and currents (high energy) whereas flat nodules are developed in less energetic environments (Bosselini and Ginsburg, 1971). Rhodolith shape may be indicative of the frequency of movement irrespective of environmental conditions (Reid and Macintyre, 1988). The frequency of movement, however, does not convey the strength of such events (Prager and Ginsburg, 1989). Rhodoliths may be continuously overturned by low energy events. In addition, spheroidal shape may not reflect constant movement. Scoffin *et al.* (1985) demonstrated that coralline algae can continue to survive on the non-illuminated surface of a rhodolith which is in contact with the substrate. This is attributed to the movement (shifting) of the supporting substrate, as no one point of the rhodolith is in direct contact with the substrate for a fatal length of time. Spherical shape appears to be a function of frequent repositioning (irrespective of water energy) or the product of a shifting substrate.

3.4 Genetic Relationship of Facies

Three depositional units (units I - III) are present in the Cayman Formation at Tarpon Springs Estates. These units, which contain genetically related facies, are bound by discontinuity and disconformable surfaces. Each unit represents a suite or package of sediment that was deposited in a well defined range of environmental conditions. Vertical facies changes in these units are gradual and therefore reflect gradual changes in environmental conditions. Abrupt changes in paleoenvironmental conditions took place between facies belonging to different depositional units. The sharp contact between depositional units represent a depositional hiatus. The presence of marine borings and dissolution cavities associated with these surfaces indicate that erosion took place during the depositional hiatus. Changes in environmental conditions resulted in the truncation of depositional units by periods of erosion.

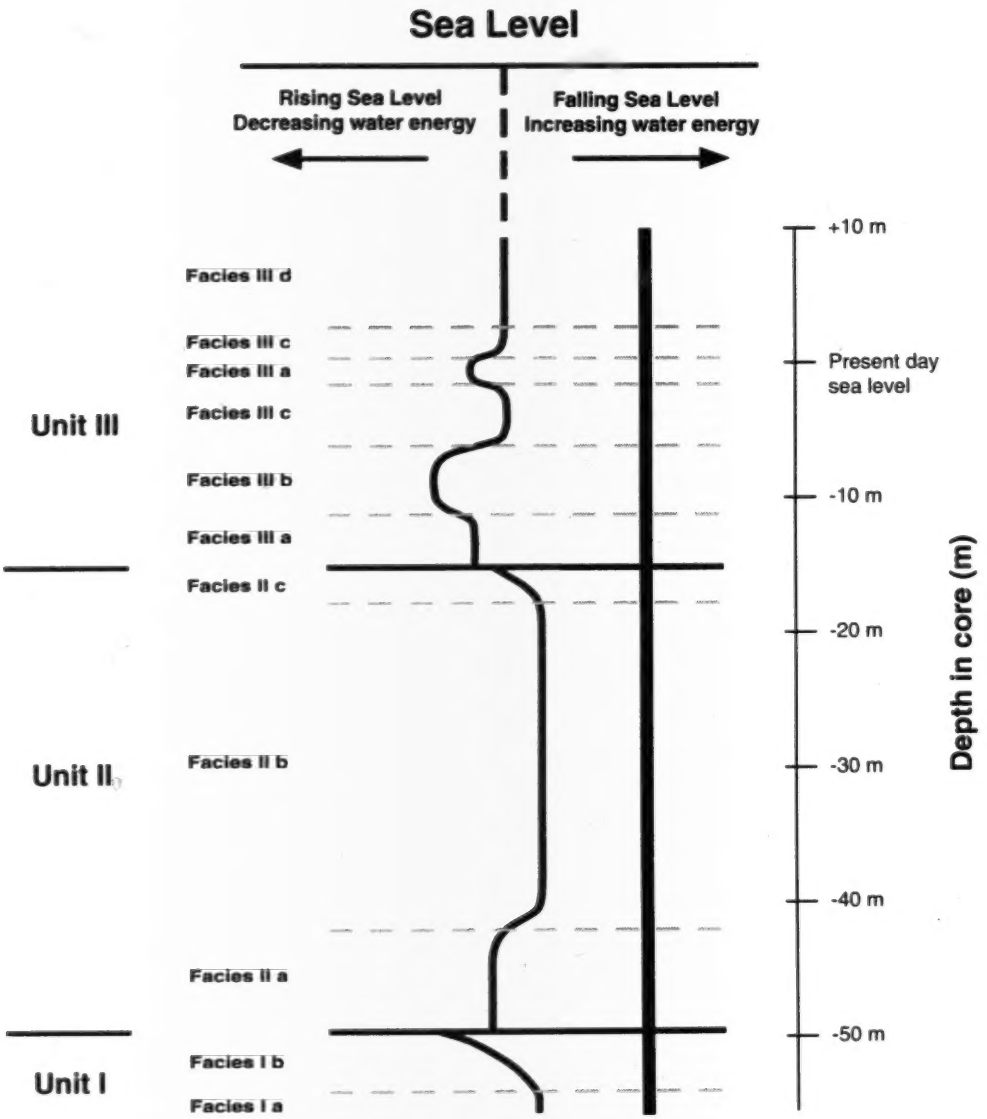

Figure 3.2: Relative sea level (water depth) and water energy curve for the Cayman Formation at Tarpon Springs Estates.

3.5 Depositional Architecture

Unit I

Sediments of the Cayman Formation were deposited under normal, shallow marine conditions on an open bank. The basal facies of Unit I consists of coralline algal and foraminifera packstone sands, deposited under relatively high energy, shallow water conditions. This facies changes vertically from packstone to wackestone foraminifera sands and records a decrease in water energy associated with an increase in water depth. These conditions led to a stable, lower energy environment colonized by branching corals and *Halimeda.*

The bounding surface at the top of Unit I is a marine hardground. Submarine cementation responsible for the formation of hardgrounds was controlled by diagenetic and depositional processes. Hardgrounds commonly develop in areas with slow sediment accumulation rates, stable substrate conditions, and relatively high water flux at the sediment-water interface but not high enough to transport or erode the stabilized sediment. The latter condition is commonly associated with strong currents, tidal or wave action (Scoffin, 1987; Tucker and Wright, 1990). The hardground surface capping Unit I was formed under different environmental conditions relative to those responsible for deposition of units I or II. An abrupt change from the apparent deepening, lower energy regime of Unit I to the shallower higher energy regime of Unit II represents a depositional hiatus (Figure 3.2). Hardground development presumably took place during this hiatus.

Unit II

The lowermost facies in Unit II was deposited under higher energy shallower water conditions compared to Unit I (Figure 3.2). This change in water energy and depth caused an increase in grain size, a decrease in the amount of mud, a change in biotic composition, and an increase in biotic abundance. The marine hardground at the top of

Unit I separates the branching coral, coralline algae (crustose and articulated) and *Amphistegina* dominated fauna (Facies Ib) from a crustose coralline algae (rhodoliths), foraminifera (*Amphistegina*, *Sphaerogypsina*, mega-amphisteginid), and rare laminar coral fauna (Facies IIa). The abundance of crustose coralline algae relative to corals in Unit II indicates the conditions were more amenable for coralline algae. These conditions allowed coralline algae to compete and exclude corals from the available substrate. High energy conditions and low sediment accumulation rates of Unit II would result in the development of a shifting substrate. The existence of a reworked, rapidly shifting substrate would account for the paucity of corals and the abundance of spherical, laminar rhodoliths.

Sediment burial and increased water turbidity are detrimental to photosynthetic organisms. A rapidly shifting substrate would increase water turbidity by suspending fine material trapped in the coarser sediment or fines created *in situ*. These conditions can cause the demise of corals and coralline algae preventing the formation of reefs and rhodoliths. A shifting substrate would lead to the periodic burial and exhumation of corals and rhodoliths. Upon exhumation, coralline algae could recolonize the relict rhodoliths and initiate an additional period of growth and development. Development of rhodoliths is favoured in areas of low sedimentation (Hills, pers. com.). High rates of sedimentation are capable of burying potential substrate and exisiting rhodoliths. Burial of rhodoliths can lead to the demise of the encrusting coralline algae. An abundance of rhodoliths in Unit II, therefore, indicates a period of low sediment accumulation.

An alternate explanation for the biotic change from corals to coralline algae is enhanced nutrient influx due to upwelling. Algae commonly thrive in nutrient rich waters whereas corals can better compete in nutrient poor conditions (Littler and Littler, 1985). Upwelling conditions have been inferred from the dense algal concentrations in the Miocene of southeastern Spain (Mankiewicz, 1987). Increased nutrient content around Grand Cayman due to the onset of upwelling conditions appears unlikely. Upwelling

tends to be a regional process commonly affecting larger areas than that of the study area. The abundance of coralline algae and rhodoliths in the study area is not a regionally extensive feature. Abundant coralline algae is of local importance and is not indicative of upwelling conditions.

Energy conditions continued to increase as water depth decreased during deposition of Facies IIb (rhodolith, foraminifera, crustose coralline algae and fragmented branching coral floatstone/packstone facies). The paucity of calcareous mud, and the increase in rhodolith size relative to the underlying facies of Unit II suggests a slight increase in water energy (associated with a decrease in water depth). Thus, Facies IIb was deposited under the highest energy conditions and shallowest water depths relative to all other facies of units [redacted].2). The thickness of this facies (23 m) suggests that these depositional conditions persisted for a relatively long period of time.

Depositional conditions change towards the top of Facies IIb. Free-living and massive corals, absent from the lower part increase in abundance towards the top of this facies. Free-living corals continued to increase, and became a common component in Facies IIc. The increase in numbers of free-living coral indicates development of a stable, sandy substrate because these corals typically lived with their tapered base partly buried in sand. These corals require a sandy substrate because they are not capable of shedding fine grained sediment. Free-living corals also require a relatively stable substrate that prevents them from being overturned or burried. A decrease in sediment transport due to decreased energy (increased water depth) resulted in the development of a more stable substrate enabling the establishment of free-living corals. The presence of scattered free-living coral fragments at the top of this facies indicates changing environmental conditions. The decrease in water energy responsible for these changing conditions was slight as indicated by the dense packstone matrix of the overlying facies.

Free-living corals and bivalve shells (disarticulated and/or fragmented) are present in the uppermost facies of Unit II. Corals are commonly small (less than 3 cm wide) and

appear to have been transported. Most of these corals, however, appear to be complete and as such may have originated locally. The existence of stable substrate conditions during deposition of this facies is supported by the presence of bioeroded bivalve fragments. Bioerosion of shell material requires a relatively stable substrate to allow for colonization and erosion. A shifting substrate would prevent the colonization of shell material. Bioerosion of shell material also suggests a period of low sediment accumulation. High sediment accumulation rates would bury shell material preventing colonization. The existence of low sediment accumulation rates are consistent with the abundance of rhodoliths in the two underlying facies of Unit II. This period of low sedimentation and stable substrate contributed to the development of a hardground surface at the top of the Free-living coral, bivalve, foraminifera, coralline algae floatstone/packstone facies of Unit II.

Unit III

The hardground surface at the top of Unit II separates the abundant foraminifera and rare free-living coral fauna of Facies IIc from the branching coral and *Halimeda* biota of Facies IIIa (Figure 2.3). Energy conditions remained relatively stable as the matrix above and below the hardground surface are skeletal packstones (Figure 3.2). Hardground development appears to have formed in response to a slight decrease in water energy. The hardground surface developed under relatively high energy, shallow water conditions. This is comparable to Serranilla Bank, a modern bank in the Caribbean Sea which is characterized by the presence of hardgrounds and a thin cover or veneer of sediment (Triffleman *et al.*, 1992). Low rates of sediment accumulation are attributed to the removal/transport of sediment off-bank by currents and/or waves. A slight increase in current and/or wave strength in the study area prevented the accumulation of sediment which exposed the substrate at the sediment-water interface to a prolonged period of high water flux. This period of high water flux at the sediment-water interface initiated marine

cementation and the development of the hardground surface.

A decrease in water energy and increase in depth allowed the deposition of facies in Unit III (Figure 3.2). Depositional Unit III is composed of four facies that are dominated by fragmented corals. Variations in coral fauna of the Cayman Formation have been related to substrate conditions (Jones and Hunter, 1994a). *In situ* branching corals are capable of modifying substrate conditions by baffling water energy which promotes deposition of fine grained sediment. *In situ* branching corals are relatively rare in the study area. Fragmented branching corals, abundant in Unit III, are not capable of baffling water energy to the extent of *in situ* branching corals. Changes in substrate conditions affecting the study area are therefore related to variations in water energy and depth.

The lowermost branching coral, *Halimeda*, coralline algae and mollusc floatstone/ packstone-wackestone facies is dominated by *Stylophora* spp., *Porites barcoaensis,* and scattered *Montastrea* fragments. The matrix of this facies changes from a packstone matrix at the base to a wackestone matrix towards the top. This change suggests a decrease in water energy and increase in water depth.

The overlying three facies of Unit III record a gradual increase in water energy accompanied by a decrease in water depth (Figure 3.2). The matrix of each successive facies contains less fine grained sediment relative to the underlying facies. The coral fauna changes from massive to branching forms and finally to a combination of branching and rare massive forms. Facies changes are gradual suggesting lateral and vertical variability.

3.6 Regional Comparisons of the Cayman Formation

The sedimentology and depositional architecture of the Cayman Formation at Tarpon Springs Estates is similar to that described from the Safe Haven area of Grand Cayman and directly comparable to the Cayman Formation on Cayman Brac. In the absence of any evidence supporting the existence of a regional dip, the Cayman

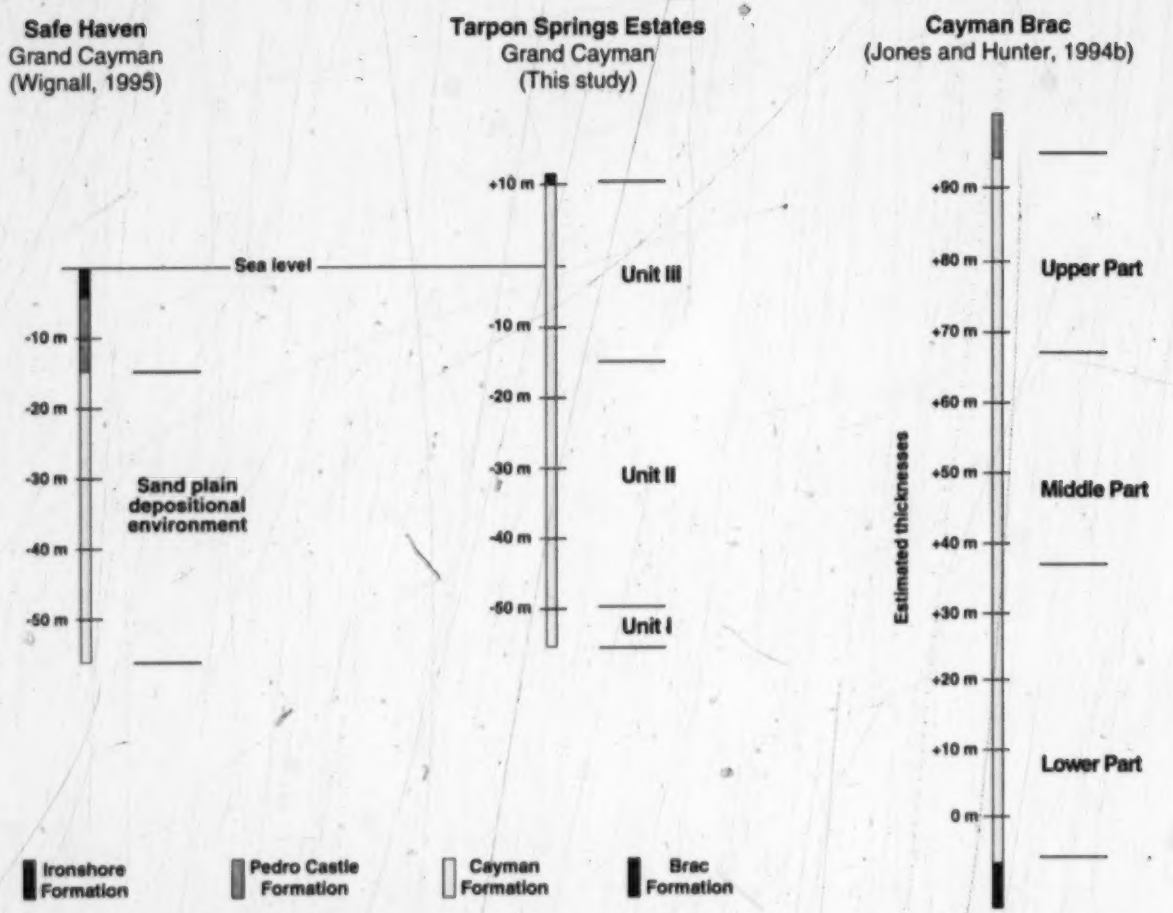

Figure 3.3: Tentative correlation of the Cayman Formation at Safe Haven, Tarpon Springs Estates and Cayman Brac.

Formation on Grand Cayman is considered to be horizontal. The Cayman Formation in the Safe Haven area (42 m thick) is stratigraphically equivalent to the lowest part of the succession (41 m) from the Tarpon Springs area (Figure 3.3). Wignall (1995) suggested that the Cayman Formation in the Safe Haven area formed in the Sand Plain, Near Reef, and *Porites* Reef environments. The Sand Plain is the most extensive environment (laterally and vertically), being present throughout the Safe Haven Area. The *Porites* Reef and Near Reef environments developed in isolated areas that were surrounded by the Sand Plain environment (Wignall, 1995).

The Sand Plain environment in the Safe Haven area is composed of skeletal packstones, grainstones, and rare wackestones dominated by *Amphistegina*, coralline algae, *Halimeda,* and molluscs. Branching corals (*Stylophora, Porites*) are rare in this environment. Sediments of the Sand Plain environment display lateral variability because they commonly interfinger on a meter scale; however, large scale lateral variations in the distribution of allochems are not readily discernible (Wignall, 1995). An isolated *Porites* reef (*Porites* reef environment) is developed in the Sand Plain environment of the Safe Haven area. This reef, approximately 10 m thick and 300 m wide, extends in a north - south direction for at least 1 km (Wignall, 1995). The Near Reef environment, which surrounds the *Porites* Reef environment, is composed of reef talus. This environment is differentiated from the Sand Plain environment by an abundance of *Porites* fragments and proximity to the *Porites* reef.

The biota in the Safe Haven Sand Plain environment is similar to that of depositional units I and III at Tarpon Springs Estates. This similarity suggests that units I and III may represent a similar depositional environment. The Safe Haven Sand Plain environment contains rare, scattered coral fragments. Coral abundance in the Safe Haven area increases with proximity to the Near Reef and *Porites* Reef environments. The abundance of fragmented corals in Unit III of the study area relative to the Safe Haven Sand Plain environment does not represent proximity to a 'near reef' environment. Coral

fragments in Unit III of the study area display a high species diversity and no *Porites* reef is evident. Coral abundance in Unit III and the rest of the study area is the result of increased coral development in an environment similar to the Safe Haven Sand Plain. Further comparisons between Unit III and the Safe Haven Sand Plain environment are, however, limited because these areas are not stratigraphically equivalent (Figure 3.3). The Cayman Formation of the Safe Haven and Tarpon Springs areas has been eroded. Subareal exposure during the Messinian subjected the Cayman Formation to a period of karstification. The western part of Grand Cayman (including the Safe Haven area) experienced a higher rate of dissolution relative to the eastern part (Tarpon Springs area) of the island (Jones and Hunter, 1994b). Unit III of the study area represents a period of deposition that was removed by erosion in the Safe Haven area.

Unit II, approximately 35 m thick, is equivalent to the uppermost 35 m section at Safe Haven (Figure 3.3). Unit II is dominated by rhodoliths whereas they are relatively rare at Safe Haven. Rhodoliths are restricted to a 5 m interval in well SH #3 (35 - 40 m bsl) where they are associated with lithoclasts (Wignall, 1995). The restricted nature (laterally and vertically) and evidence of erosion (lithoclasts) suggets deposition under relatively brief, high energy conditions, possibly a storm (Wignall, 1995).

Rhodoliths in Unit II of the study area (facies IIa and IIb) form thick deposits (30 m) that are not associated with lithoclasts and are laterally continuous between wells SOT #1 and SOT #2. Unit II accumulated under different environmental conditions relative to the Sand Plain environment of Safe Haven. The study area is located on the windward margin of the island and the dominance of rhodoliths and paucity of corals in Unit II is attributed to the existence of a shifting substrate. The Safe Haven depositional environment was situated on the sheltered western peninsula. Reefal development in the Safe Haven area suggests the existence of more stable substrate conditions relative to Tarpon Springs Estates.

Comparisons can also be made between the Cayman Formation at Tarpon Springs

Estates and the Cayman Formation of Cayman Brac. The Cayman Formation on Cayman Brac, estimated to be 100 m thick, has been informally divided into lower, middle, and upper parts (Jones and Hunter, 1994b) (Figure 3.3). The lower part of the Cayman Formation, approximately 45 m thick (Jones and Hunter, 1994b: Figure 11), is composed of coralline red algae wackestones and packstones containing corals, bivalves, and gastropods. Corals are dominated by massive forms with lesser numbers of laminar and branching corals (Jones and Hunter, 1994b). Unit I (6 m thick), at Tarpon Springs Estates contains a similar fauna to the lower part of the Cayman Formation of Cayman Brac.

The middle part of the Cayman Formation on Cayman Brac, estimated to be 35 m thick (Figure 3.3), is dominated by bioclastic wackestones and packstones with abundant rhodoliths (Jones and Hunter, 1994b). Rhodoliths are found in beds and lenses filling small erosional channels/depressions. Unit II in the Tarpon Springs area is approximately equal in thickness and contains similar allochems. Rhodoliths in the study area are associated with an erosional (hardground) surface and are found in relatively thick (30 m), continuous strata with no apparent bedding or internal lamination. The rhodoliths from Cayman Brac have fragments of *Stylophora* and *Porites* as nuclei. These rhodoliths probably formed in water less than 30 m deep (Jones and Hunter, 1994b). Rhodoliths from Tarpon Springs Estates have nucleated on coralline algae fragments and to a lesser extent on branching coral fragments. Modern rhodoliths with coralline algae nuclei occur in water depths greater than 40 m in the Gulf of Mexico (Reid and Macintyre, 1988). The material serving as nuclei is a function of availability, not depth. Rhodoliths in Unit II formed in an area with rare corals under similar conditions to those responsible for deposition of the middle part of the Cayman Formation on Cayman Brac.

The upper part of the Cayman Formation on Cayman Brac, estimated to be 20 m thick (Figure 3.3), is dominated by massive and branching corals. Branching corals are situated in mudstone matrices whereas massive corals are situated in wackestone and packstone matrices. Foraminifera, bivalves, coralline algae, gastropods, echinoids, and

Halimeda are common skeletal components in the matrix (Jones and Hunter, 1994b). Unit III at Tarpon Springs Estates, approximately 26 m thick (Figure 3.3), is dominated by branching and massive corals with scattered free living corals. Branching corals are found in wackestone and packstone matrices whereas massive corals are found in a wackestone matrix. Associated with this coral fauna are foraminifera, coralline algae, *Halimeda*, bivalves, echinoids, and gastropods.

Units II and III in the study area are directly comparable to the middle and upper parts of the Cayman Formation of Cayman Brac in biotic composition and in thickness. These areas may be stratigraphically equivalent with differences in elevation (relative to sea level) attributed to the uplift of Cayman Brac. Unit I contains a similar fauna to the lower part of the Cayman Formation on Cayman Brac. The vertical and lateral extent of Unit I is unknown at this time because it is restricted to well SOT #2. Comparisons of thickness can not be made between Unit I and the lower part of the Cayman Formation of Cayman Brac.

The Cayman Formation described from the study area is comparable to that of Cayman Brac. The Cayman Formation on Cayman Brac accumulated in waters 15-30 m deep with good cross bank circulation (Jones and Hunter, 1994b). Facies present in the Cayman Formation at Tarpon Springs Estates accumulated under similar conditions as suggested by the presence of similar fauna. Cayman Brac and Tarpon Springs Estates are both characterized by a lack of large scale reefal development. The lack of reef development in the study area is attributed to the existence of a rapidly shifting substrate reflecting periods of high energy. The lack of reef development on Cayman Brac has been attributed to high energy conditions which prevented the settlement of coral larvae (Jones and Hunter, 1994b).

Modern Caribbean banks in waters deeper than 15 m are characterized by a sponge-algal fauna, the development of hardgrounds (Triffleman *et al.*, 1992) and thin accumulations of sediment (Glaser and Droxler, 1991; Triffleman *et al.*, 1992). Corals

are rare or development is restricted to windward margins. Despite the lack of coral reef development carbonate production on these banks is high (Glaser and Droxler, 1991). Thin accumulations of sediment are the result of off-bank transport of sediment due to current and wave activity. By comparison, the Cayman Formation at Tarpon Springs Estates contains a similar fauna which accumulated in similar water depths to those of modern Caribbean banks. The depositional succession in the study area also contains two hardground surfaces which suggest periods of low sediment accumulation. The Cayman Formation in the study area, however, differs from modern Caribbean banks in that it represents a thick package of sediment. Periods of low sediment accumulation (discontinuity surfaces) in the Cayman Formation of the study area were relatively rare, of short duration and interspersed between periods of high sedimentation which deposited a minimum of 65 m of sediment in the study area. Bedding is absent in the study area and facies changes are gradual except where capped by a hardground surface. Sedimentation within each depositional unit appears to be continuous with no discernible breaks or hiatuses. Development of thick sedimentary packages in the Cayman Formation at Tarpon Springs Estates could be the result of bank sheltering (Wignall, 1995) or net on-bank transport of sediment from off-shore areas by currents and waves. The continuous nature of these sedimentary packages suggests relatively constant depositional conditions. Accomodation space must have remained relatively constant throughout the depositional period. This suggests that sea level fluctuations and/or subsidence paralleled the rate of sediment accumulation in the study area.

Windward margins of partially drowned (> 15-20 m water depth) modern Caribbean banks tend to be sites of limited coral development. These margins are also characterized by a net energy flux onto the platform which may result in the formation of skeletal sand bodies (Hine, 1983). The Cayman Formation in the study area accumulated along the windward margin. The apparent lack of constructional features in the area precludes the possibility of bank sheltering. Thick accumulations of sediment in the

study area is presumably the result of on-bank transport and bioturbation (homogenization) of the sediment in an area of relative constant accomodation space.

3.7 Synopsis

Carbonate sediment that forms the Cayman Formation at Tarpon Springs Estates was deposited in normal marine water on an unrimmed, open bank. The coarse grain size, presence of a diverse photosynthetic biota and apparent lack of mud in the Cayman Formation of the study area suggests deposition took place under moderate to high energy conditions in water 10 - 35 m deep.

Depositional Unit I in the Cayman Formation of the study area was deposited under relatively high energy, shallow water conditions. These environmental conditions change towards the top of this unit. Unit II was deposited under higher energy, shallower water conditions relative to Unit I. Depositional conditions change towards the top of this unit as water energy appears to decrease. Unit III was deposited at greater water depths and lower energy conditions relative to Unit II.

Depositional units I and III of the Cayman Formation at Tarpon Springs Estates were deposited under similar conditions to those of the Sand Plain environment on the western peninsula (Wignall, 1995). Unit II of the study area accumulated under different environmental conditions in the presence of a shifting substrate.

Depositional units II and III in the Cayman Formation of the study area are directly comparable to the middle and upper parts of the Cayman Formation on Cayman Brac. These successions in the study area and on Cayman Brac are comparable in thickness and in the occurrence and distribution of allochems. These similarities suggest that the two areas represent similar depositional environments.

Chapter 4

Sedimentology and Depositional Architecture of the Ironshore Formation

4.1 Introduction

The Ironshore Formation was named by Matley (1924, 1925a, 1925b) after the Caymanian term for the hard rocky shore that formed along the coastal platform of Grand Cayman. This formation is composed of four members (A - D) that were deposited during sea level highstands associated with the last four interglacial periods (Vézina, 1996; Vézina *et al.*, 1997). The Ironshore Formation in the study area corresponds to Member D, the youngest member. These Pleistocene limestones were deposited during the Sangamon highstand (approximately 125,000 years ago) when sea level was 6 m above the present day level. Areas of Grand Cayman more than 6 m above present day sea level remained subaerially exposed whereas those areas below +6 m were flooded by sea water (Hunter and Jones, 1988). This produced a large lagoon on the western part of the island that was protected by a peripheral ridge to the north, east and south and by a barrier reef to the west (Figure 4.1). This lagoon is known as the Ironshore Lagoon (Hunter and Jones, 1988; Hunter and Jones, 1989).

Widespread shallow water carbonate deposition in the Ironshore Lagoon resulted in the development of a gradual shallowing upward sequence (Jones and Hunter, 1989). This sequence was deposited in water with a maximum depth of 8 to 10 m (Shourie, 1993).

4.2 Sedimentology

Limestones of the Ironshore Formation (up to 2 m thick) are exposed at the surface of Tarpon Springs Estates except in the area of the peripheral ridge. These limestones,

which cover the underlying Cayman Formation, are capped by a 0.5 - 2 cm thick laminar calcrete.

Drilling in the study area penetrated 2 m of Ironshore limestone in SOT #1 and 1.6 m in SOT #2 with poor recoveries (0 and 6 % respectively) due to their soft and friable nature. This sequence represents the basal part of the formation given that higher strata was presumably lost to erosion associated with subareal exposure. No vertical exposures of the Ironshore Formation are present in the study area. *In situ* surface samples were collected throughout the study area and additional observations were made from limestones exposed above the water level on the sides of the dredged pit. Two samples were collected from large (approximately 2 m diameter) boulders, that lay beside the dredged pit.

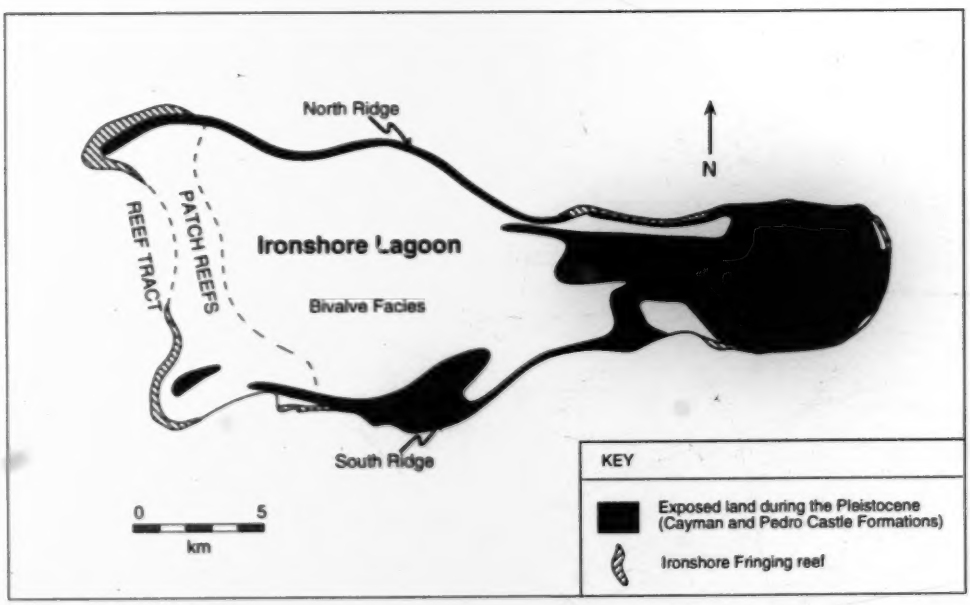

Figure 4.1: Paleogeography of the Ironshore Formation (modified from Hunter and Jones, 1988).

The most prominant feature of the Ironshore Formation in the area is the thin (0.5 - 2 cm) surficial layer of laminar calcrete. Laminae, which are less than 1 mm thick, are highlighted by their grey, black and orange-brown colours that sharply contrast with the white and cream coloured limestones of the Ironshore Formation. Laminae colour in the calcrete crust is attributable to the inclusion of organic material and trace elements (Fe and Mn). This laminated calcrete crust forms an impermeable surface layer such that rain water flows laterally on the surface before entering the vadose zone through holes that penetrate the crust.

Root borings in the Ironshore Formation are lined with laminated crusts termed rootcrete by Jones (1992a). Rootcrete crusts, commonly less than 1 cm thick, are well cemented relative to the surrounding friable limestone of the Ironshore Formation. These crusts consist of light and dark laminae and are similar in appearance to surficial calcrete crusts developed in the study area. Rootcrete is differentiated from calcrete, as crusts of the former have a random orientation and their development is specific to root borings. The formation of rootcrete crusts differs from calcrete crusts as rootcrete is formed from the diagenetic segregation (Arakel, 1982), incorporation and cementation (Squair, 1989) of soil components whereas calcrete crusts are *in situ* pedogenic carbonate accumulations.

4.2.1 *Facies of the Ironshore Formation*

Facies in the Ironshore Formation of Tarpon Springs Estates have been previously described by Hunter and Jones (1988), Cerridwen (1989), Jones and Hunter (1990), Shourie (1993), and Hunter (1994). Samples collected from the Ironshore Formation at Tarpon Springs Estates are composed of molluscan rudstones that have been assigned to the Bivalve facies (Hunter and Jones, 1988; Jones and Hunter, 1990). Bivalves are of variable size (less than 1 cm - 16 cm wide) and are commonly articulated. A high diversity (56 species) biota dominated by *Anodonta alba*, *Chione*, *Codakia costata*, *Linga*

pensylvanica, *Tellina*, *Bulla striata*, *Cerithium*, and *Nassarium albus* is present in the study area (Cerridwen, 1989; Cerridwen and Jones, 1990). This assemblage represents a burrowing bivalve fauna, dominated by infaunal suspension and deposit feeding forms and free living gastropods (Cerridwen, 1989; Cerridwen and Jones, 1991). Molluscan fragments are situated in a variable wackestone to packstone matrix composed of very fine sand and calcareous silt with numerous foraminifera (predominantly peneroplids and miliolids). Molluscan shell fragments (< 2 mm) and *Halimeda* are common in the matrix. The latter are commonly surrounded by micritic envelopes.

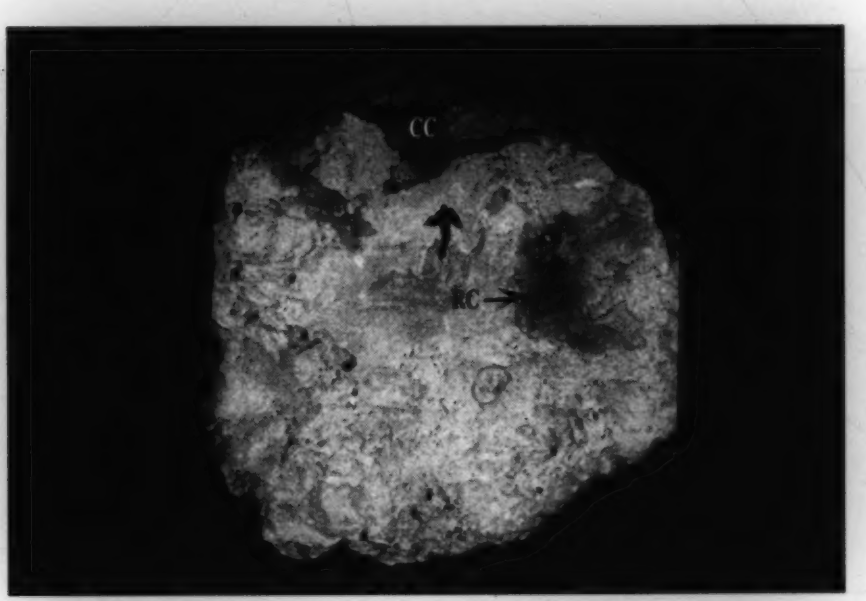

Figure 4.2: Sample of the Ironshore Formation from Tarpon Springs Estates displaying surficial calcrete crust (CC) and laminated rootcrete (RC) developed around a rhizolith.

Although rare colonies of *Siderastrea* and *Porites* have been described from the study area (Hunter, 1994), none were found during the course of this study.

4.3 Depositional Environment

The molluscan fauna in the study area is abundant and closely packed. Bivalves and gastropods are well preserved with little evidence of abrasion and breakage. Bivalves of variable sizes are commonly preserved in an articulated condition with lesser numbers being disarticulated and/or fragmented conditions. Bivalve fragments in the study area (> 2 mm) are commonly derived from *Tellina* spp. which has a relatively thin shell that is more prone to abrasion and breakage (Cerridwen, 1989). Small (< 2 mm) mollusc fragments in the matrix were derived from 'thin shelled species' or were transported into the depositional area during phases of high energy. Nevertheless, the dominance of densely packed, articulated specimens indicates a lack of physical transport. Of the samples collected from Tarpon Springs Estates, approximately 56% of the taxa are known to be burrowers (Cerridwen, 1989). The lack of physical transport and dominance of burrowing forms in the study area suggests an *in situ* burrowing community. This mollusc community and the fine grained sediment (fine sand - mud) of the matrix suggests that deposition took place in a protected, low energy, shallow water setting.

Deposition of the Ironshore Formation in the study area took place in the extreme eastern part of the Ironshore Lagoon when sea level was +6 m above the present day level (Figure 4.1). The Ironshore Formation in the study area extends from sea level to -2 m bsl indicating deposition took place in a water 6 - 8 m deep.

The Ironshore Lagoon was dominated by a diverse mollusc assemblage which included epibiont species specific to *Thalassia* (e.g., *Tricolia thalassicola*). These epibionts indicate that sea grass banks composed of *Thalassia* were developed in the lagoon (Hunter and Jones, 1996). Sea grass banks would have baffled water energy in

the lagoon promoting deposition of fine grained (silt and mud) sediment. The diverse mollusc community, *Thalassia*, and rare corals present in the Ironshore Formation of the study area is similar to that of landward parts of modern lagoons developed around Grand Cayman.

Waters of the Ironshore Lagoon in the study area were of normal to slightly elevated salinity as suggested by the foraminifera assemblage and the paucity of corals. The abundance of fine grained sediment in the study area and the unrestricted - slightly restricted water conditions (as indicated by normal to slightly elevated salinity levels) suggest the existence of moderately turbid water conditions.

Chapter 5

Diagenesis of the Cayman Formation at Tarpon Springs Estates

5.1 Introduction

Dolostones in the Cayman Formation on Grand Cayman have been modified by a variety of diagenetic processes. The complex array of fabrics produced during diagenesis have commonly obscured and/or masked the original nature of these rocks (Jones, 1994). Many of these fabrics have been described by Jones *et al.*, 1984, Jones *et al.* (1989), Pleydell (1987), Pleydell *et al.* (1990), Ng (1990), Ng *et al.* (1992) and Wignall (1995). With the exception of Wignall (1995), these studies have been limited to data derived from coastal exposures, quarries or chip samples from shallow wells (less than 16 m bsl). This study follows the lead of Wignall (1995) and utilizes subsurface data generated from a drilling program on Grand Cayman. Analysis of cores recovered from Tarpon Springs Estates provides the stratigraphic framework for investigating the diagenetic processes that have affected strata in the study area.

5.2 Description of Diagenetic Fabrics in the Cayman Formation

5.2.1 *Matrix Dolomites*

Two types of dolomite form the matrix of the dolostones in the Cayman Formation at Tarpon Springs Estates. Type 1 matrix dolomite (Wignall, 1995) is composed of a finely crystalline (5 - 15 μm long) groundmass of subhedral to anhedral crystals with scattered euhedral crystals (Figure 5.1A). These crystals have a cloudy center due to inclusion of solid relicts of precursor calcite (Ng, 1990). Type I matrix dolomite is found throughout the Cayman Formation at Tarpon Springs Estates (Figures 5.2 - 5.4). Replacement of the matrix and allochems by Type I matrix dolomite was commonly a fabric retentive process. This matrix dolomite is similar to that described by Ng (1990)

and the Type I dolomite described by Wignall (1995).

Type II matrix dolomite (Wignall, 1995), is composed of euhedral to subhedral crystals 15 - 50 µm long. These dolomite crystals are commonly zoned with a cloudy core surrounded by a clear rim of dolomite (Figures 5.1C and 5.1D). At Tarpon Springs Estates, Type II matrix dolomite in the Cayman Formation has a random distribution (Figure 5.2 - 5.4). This type of matrix dolomite is found as isolated crystals (rhombs) scattered throughout Type I matrix dolomite or in clusters in small areas that are surrounded by Type I matrix dolomite (Figure 5.1B). Replacement of the matrix and allochems by Type II matrix dolomite is commonly a fabric-destructive process (Wignall, 1995).

These two types of matrix dolomite in the Cayman Formation are probably the result of separate dolomitization events (Wignall 1995). The pronounced differences in crystal morphology and fabric (Type II crystals are larger and commonly found encased in Type I matrix) and the presence of palimpsest remnants of Type I matrix dolomite encased in Type II matrix dolomite indicates separate dolomitization events. Type II matrix dolomite appears to have formed from the recrystallization of Type I matrix dolomite (Wignall, 1995).

5.2.2 *Fossil Preservation*

Preservation of skeletal components in the Cayman Formation is variable. Some skeletal components are replaced by dolomite whereas others are partly or completely dissolved and evident only as molds. Preservational differences (including fabric preservation) in the Cayman Formation have been attributed to precursor mineralogy (Pleydell, 1987; Pleydell *et al.*, 1990; Wignall, 1995). Skeletal components originally composed of high to intermediate Mg calcite were commonly replaced by fabric retentive dolomite whereas those composed of aragonite were leached and preserved as molds.

Coralline red algae and echinoid fragments have been replaced by fabric retentive

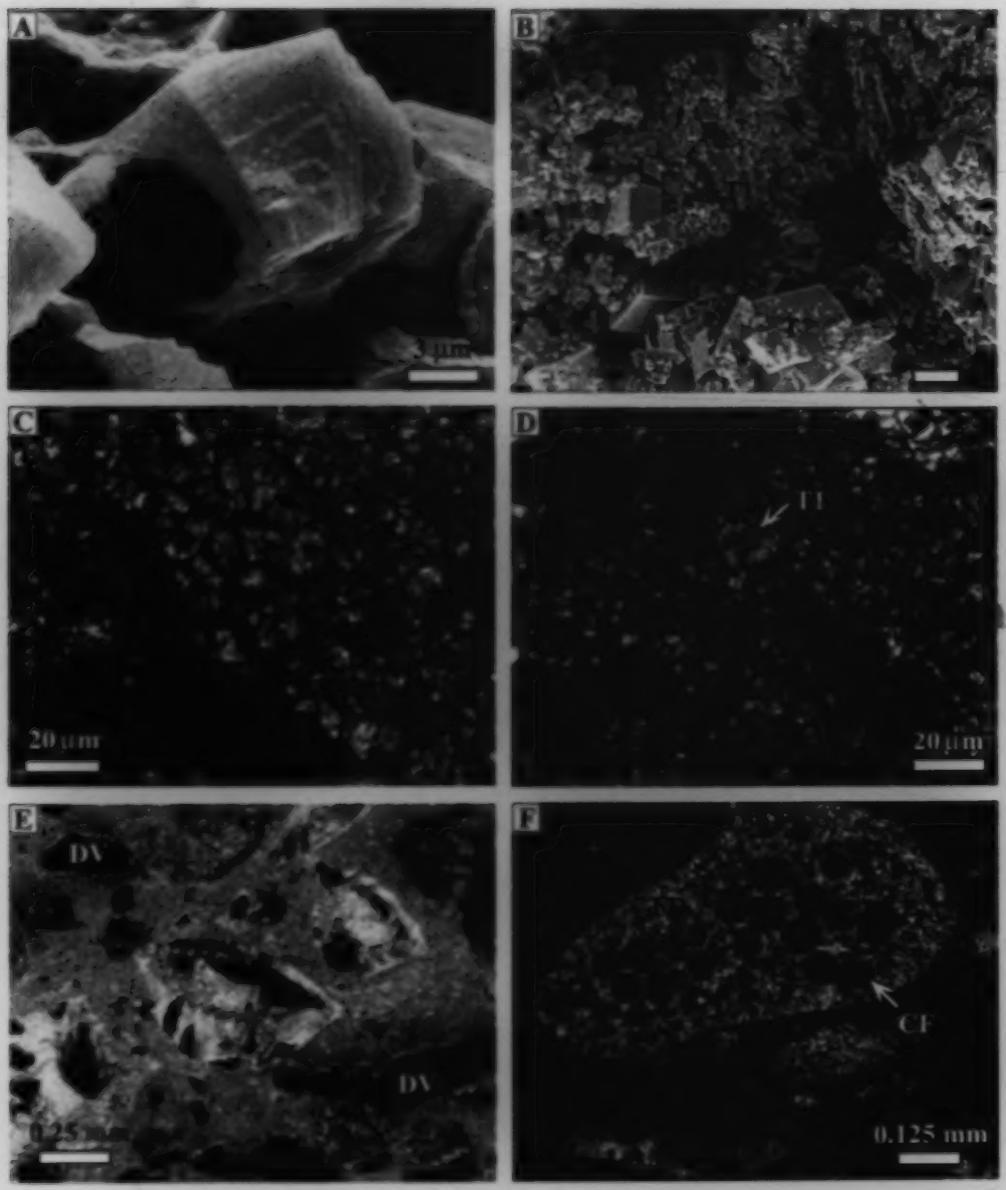

Figure 5.1: SEM images and photomicrographs of the Cayman Formation

(A) SEM image of hollow Type 1 matrix dolomite rhomb (56' 4" SOT #3)
(B) SEM image of Type 1 (T1) and Type 2 (T2) matrix dolomite (92' SOT #1)
(C) Euhedral - subhedral Type 2 matrix dolomite crystals (50' SOT #2)
(D) Type 1 matrix dolomite crystal (T1) encased in Type 2 matrix dolomite (139' SOT#1)
(E) *Amphistegina* replaced by fabric-retentive Type 1 matrix dolomite, note dissolution voids (DV) (130' SOT #2)
(F) *Halimeda* containing dolomitized cavity filling sediment (CF) and fabric-destructive dolomite (FD) (23' SOT #3)

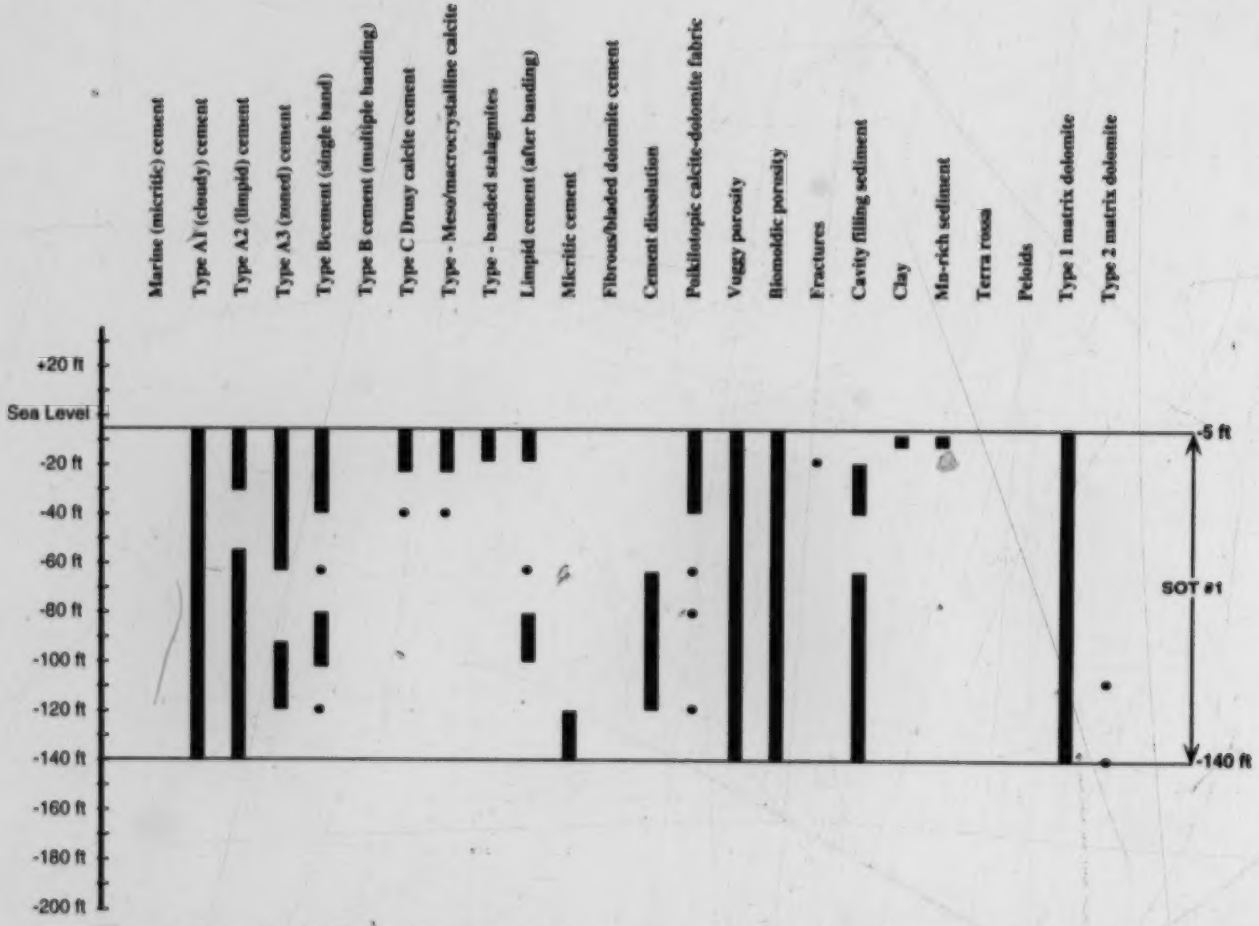

Figure 5.2: Distribution of diagenetic fabrics in the Cayman Formation in well SOT #1 as seen in thin section.

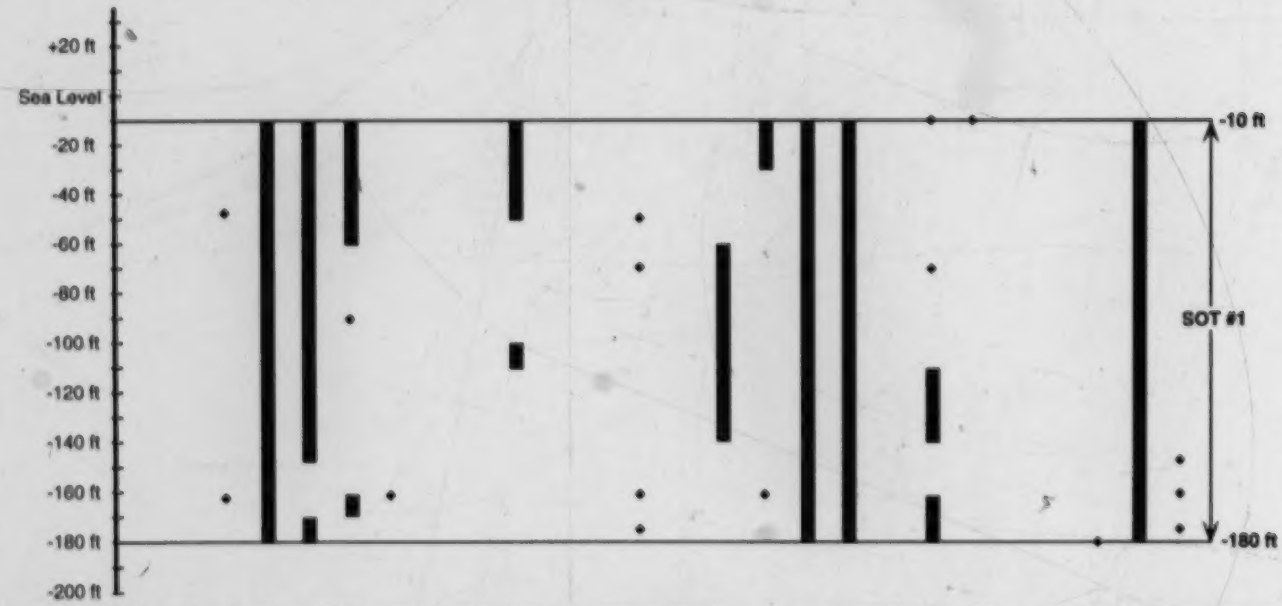

Figure 5.3: Distribution of diagenetic fabrics in the Cayman Formation in well SOT #2 as seen in thin section

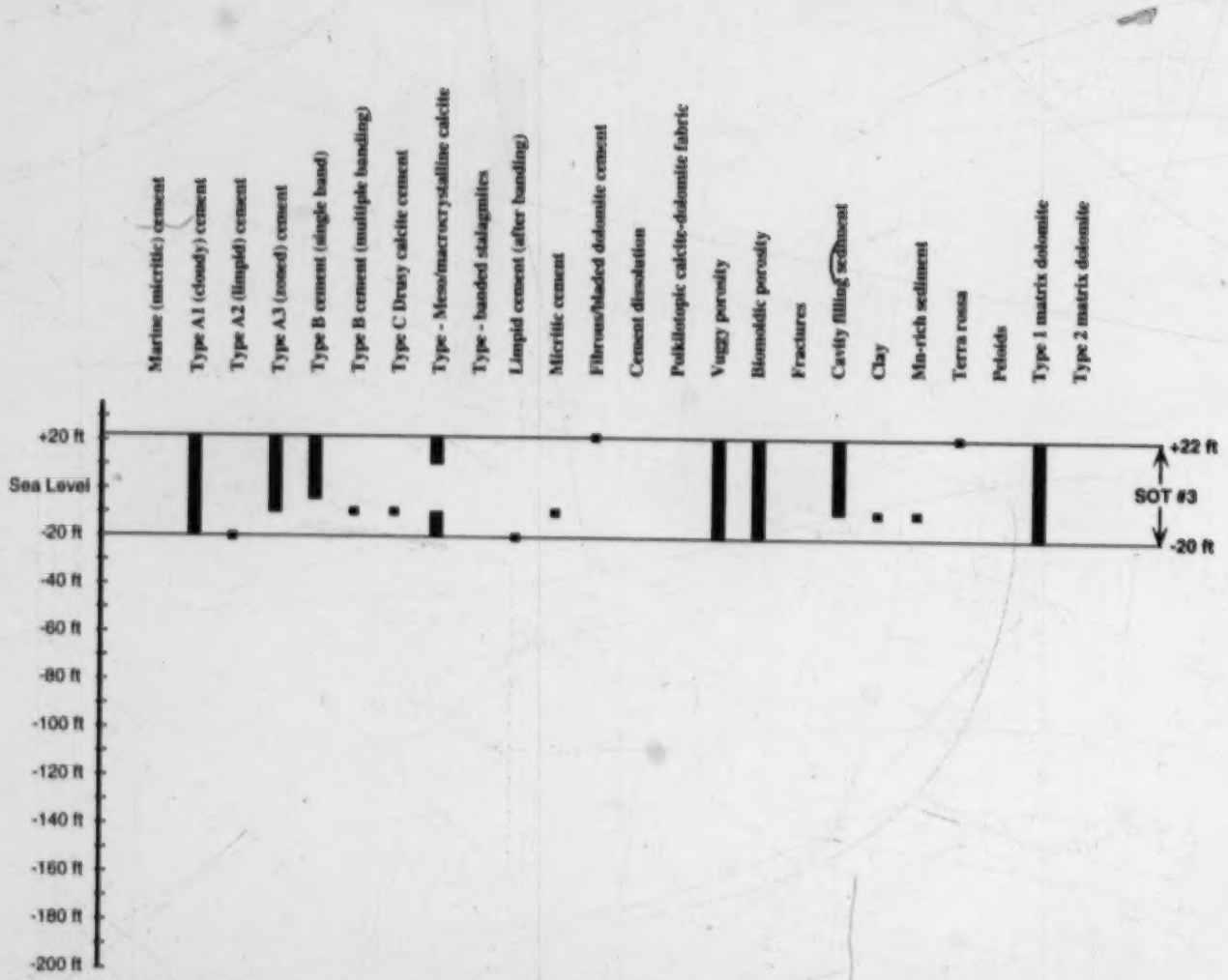

Figure 5.4: Distribution of diagenetic fabrics in the Cayman Formation in well SOT #3 as seen in thin section.

dolomite. Coralline algae has been replaced by fine grained Type I matrix dolomite, commonly less than 3 μm long. Echinoid plates and spines originally composed of single crystals are replaced by a single dolomite crystal. *Amphistegina,* a common allochem in the Cayman Formation, is composed of 5-8 mole % $MgCO_3$ (Sibley, 1982). Preservation of *Amphistegina* in the Cayman Formation varies from complete replacement to complete dissolution (Figure 5.1E). These preservational differences are not related to distinct zones or areas because they are commonly found in the same thin section. Preservation, however, may be a function of the $MgCO_3$ content. *Amphistegina* that are well preserved may have had a higher mole $MgCO_3$ content relative to those that are dissolved.

Corals, gastropods, and bivalves, originally composed of aragonite, are leached and preserved as molds (Figure 5.8A). Corals are commonly preserved as negative molds because fine grained sediment filled the interseptal voids preserving the coral structure (Pleydell, 1987). This mode of preservation, termed 'inverse porosity' (Buchbinder, 1975) or 'reversal phenomena' (Supko, 1977), commonly allows coral identification to the genus level. By comparison, gastropods are preserved as internal and external molds. This form of preservation generally precludes identification.

Halimeda, originally composed of aragonite, is a common allochem in the Cayman Formation of the study area. This skeletal allochem exhibits marked preservational differences relative to other aragonitic allochems. *Halimeda* may be dissolved and preserved as molds or may be preserved by a combination of cavity filling sediment and finely crystalline fabric destructive dolomite (Figure 5.1F). Micrite commonly filled the hollow tubules in the *Halimeda* plate prior to diagenesis. This sediment was subsequently replaced by fine grained dolomite whereas other areas of the allochem are replaced by fabric destructive dolomite.

5.2.3 *Fabric Preservation*

Dolomitized skeletal components have commonly been replaced by fabric retentive dolomite whereas rare specimens have been replaced by fabric destructive dolomite. Preservation of the form and internal structure of an allochem is mimic replacement (Kaldi and Gidman, 1982). This form of dolomite replacement is dependant on the number of nucleation sites (Sibley, 1982) which is unrelated to mineralogy. The number of nucleation sites increases as the number of crystals increases. As the number of nucleation sites increases so does the number of dolomite crystals that are able to form. Mimic replacement requires a high density of dolomite nuclei to preserve the crystallographic orientation of an allochem (Sibley, 1982). This condition is satisfied when the precursor carbonate has a high density of active nucleation sites and/or when the solution is supersaturated with respect to dolomite. These conditions also promote the transformation of $CaCO_3$ to dolomite (Sibley, 1990).

Cryptocrystalline (< 4μm) skeletal components, irrespective of mineralogy, possess more potential dolomite nucleation sites relative to microcrystalline (4 - 64 μm) skeletal components. The former have a greater surface area and contain more crystals per unit area relative to microcrystalline sized crystals. Coralline red algae, and *Amphistegina* in the Cayman Formation all possessed a cryptocrystalline skeletal structure and are commonly replaced by fabric retentive dolomite. *Amphistegina*, where preserved, has undergone mimic replacement. Evidence for mimic replacement is seen in the sweeping extinction pattern which has been preserved in the dolomite. Mimic replacement of *Amphistegina* has also been described from the Pliocene Seroe Domi Formation of Bonaire (Sibley, 1982). *Halimeda* and coralline red algae have a randomly arranged skeletal microstructure. Due to this initial random arrangement it cannot be determined if replacement preserved the original microstructure.

5.2.4 *Peloids*

Round to oval shaped structureless masses (50 - 400 μm long) are present in the Cayman Formation at Tarpon Springs Estates (Figure 5.5A). These scattered peloids are distinguished by their darker colour relative to the surrounding dolomitic groundmass. Some peloids are surrounded by a finer crystalline rim of dolomite as suggested by the darker colour, which may represent diagenetically altered micritic envelopes.

Peloids in the Cayman Formation of the study area are restricted to cavities in well SOT #2 at 54 m bsl and in SOT #1 at 2 m bsl. The origin of these peloids is unclear; however, some are associated with dolomitized filaments and may have formed as a result of their breakdown (Pleydell, 1987).

5.2.5 *Marine Cements*

Two generations of marine cementation are present in the Cayman Formation at Tarpon Springs Estates. These cements were precipitated concurrently with deposition or during depositional hiatuses. In general direct evidence of marine cements is rare as they may consist of micrite sized crystals (originally of aragonite or high Mg calcite) and therefore cannot be resolved microscopically (James and Choquette, 1984).

The precipitation of marine cements in the Cayman Formation of the study area is inferred from the presence of two hardground surfaces at 49.6 m and 14.9 m bsl in well SOT #2. The presence of a sharp, irregular contact separating different facies, borings, overhanging ledges and encrustation by coralline algae indicate periods of submarine lithification.

5.2.6 *Dissolution*

Dissolution, which can take place at any time in the diagenetic history of a rock or sediment is initiated by a change in pore water chemistry (Moore, 1989). Dissolution in the Cayman Formation is pervasive and fabric selective (Wignall, 1995). This diagenetic

process affected the Cayman Formation prior to dolomitization and subsequent to dolomitization. Multiple episodes of dissolution which took place at various scales, have affected the Cayman Formation at Tarpon Springs Estates.

5.2.6a *Macroscale dissolution*

Macroscale dissolution in the Cayman Formation encompasses non fabric-selective and fabric-selective dissolution. Allochems originally composed of aragonite have been preferentially dissolved relative to high and intermediate Mg calcite allochems. Such macroscale dissolution (James and Choquette, 1984) commonly takes place in a diagenetic system with a large flux of aggressive waters. The $CaCO_3$ derived from dissolution is transported away from the dissolution site and precipitated as cement or is utilized in the dolomitization process. Non fabric-selective dissolution resulted in the formation of vugs whereas fabric selective dissolution produced molds. Vugs, found throughout the Cayman Formation of the study area, vary in size from 1 mm to greater than 15 cm. In comparison, molds (1 mm - 12 cm) are also a pervasive feature of the Cayman Formation; however, the size of molds in the study area is restricted by the size of the allochem that was leached.

5.2.6b *Microscale dissolution*

Microscale dissolution takes place in areas of slow water flux (James and Choquette, 1984). This form of dissolution precludes the development of a moldic phase. Meteoric waters become saturated or slightly undersaturated with respect to calcite due to the low water flux. In addition, $CaCO_3$ is retained in the general area where it was liberated from and may be precipitated as a cement or utilized in the dolomitization process (Moore, 1989). Cryptocrystalline skeletal components have commonly undergone varying amounts of microscale dissolution. The dense cryptocrystalline skeletal microstructure restricts fluid movement creating an area of slow water flux. This leads to the formation of microscale dissolutional voids in *Halimeda*, coralline red algae and *Amphistegina* (Figure 5.5B).

5.2.7 *Porosity*

Porosity in the Cayman Formation is laterally and vertically variable (Jones, 1992c). Qualitative estimates of porosity at Tarpon Springs Estates range from 0 - 35%. These values may be underestimated because quantitative measurements from core recovered from LV #2 (Lower Valley) with similar fabrics commonly yielded tested porosities of 35 - 48%. Porosity development in the Cayman Formation encompasses fabric selective and non-fabric selective forms similar to those described elsewhere by Choquette and Pray (1970). Primary or depositional porosity is rare and poorly preserved due to cementation, dissolution and dolomitization which have destroyed or overprinted most of it. Preserved primary porosity in the study area consists of scattered intragranular pores in foraminifera and coralline red algae.

Most porosity in the Cayman Formation of the study area is secondary in origin. Development of this porosity is controlled by the biota present (assemblage and abundance) in the Cayman Formation. Dissolution of microcrystalline aragonite allochems has created biomoldic and solution enlarged biomoldic porosity (Figure 5.8A). This porosity can be high where allochem density was high. High-Mg calcite and cryptocrystalline aragonite skeletal allochems have commonly undergone varying amounts of dissolution prior to dolomitization creating intrafossil dissolutional vuggy porosity and rare biomoldic porosity (Figure 5.5B). Pervasive non-fabric selective dissolution in the Cayman Formation produced vugs and cavities. Non fabric selective porosity also encompasses fracture porosity which is rare in the study area and where present is occluded by calcite cement (Figure 5.5C).

Porosity is best developed in Unit II, particularly in Facies IIb. Porosity development in this facies is related to depositional and diagenetic processes. An absence of mud and relative coarse grain size suggests the possible existence of high primary porosities. This porosity was exploited by diagenetic fluids which were able to pass freely through this porous network. Cementation associated with these fluids destroyed

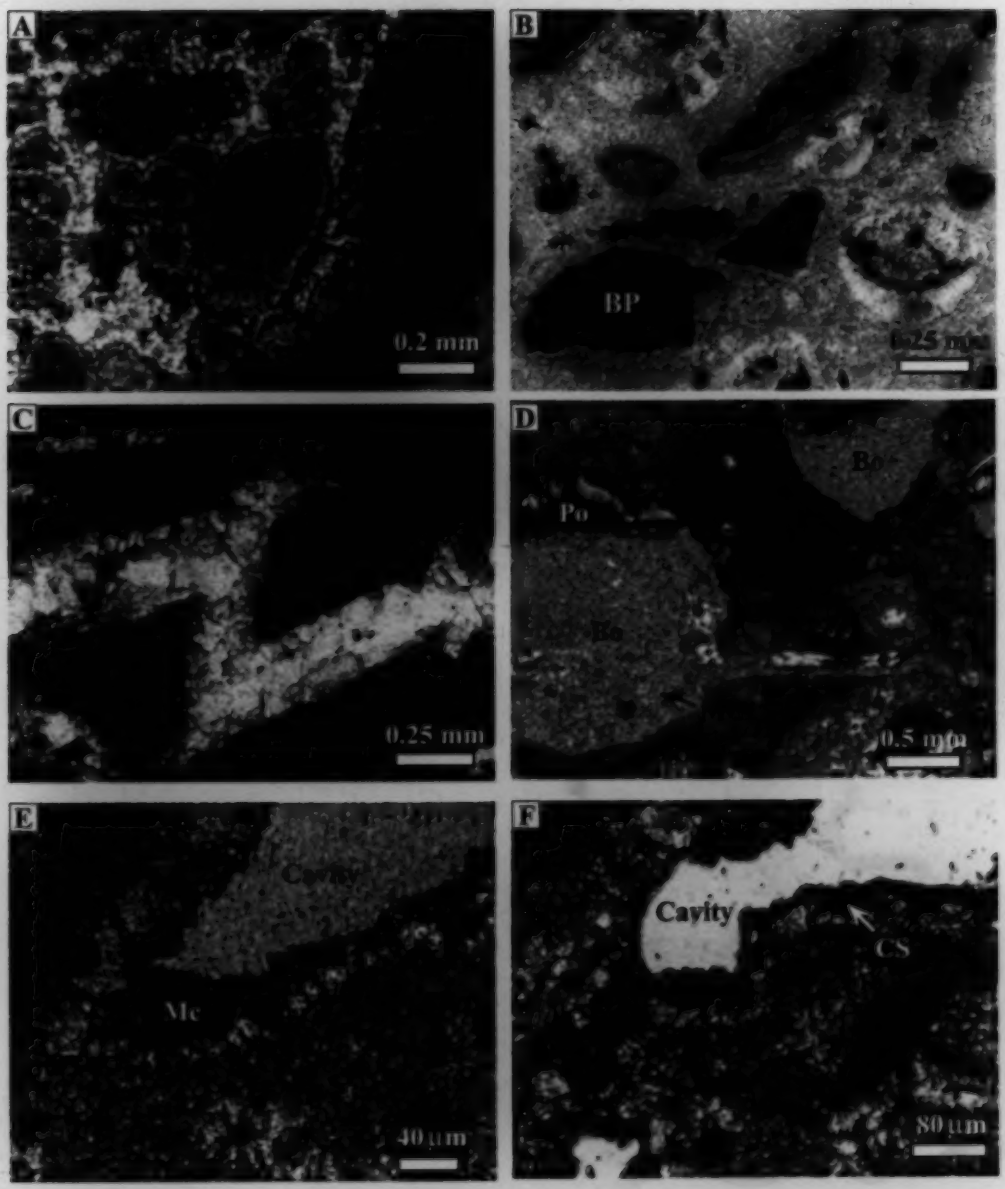

Figure 5.5 : Thin Section photomicrographs of the Cayman Formation

(A) Peloids rimmed by dolomite cement (43' SOT #3)
(B) Dissolution of *Amphistegina* creating secondary biomoldic porosity (BP) (140' SOT #2)
(C) Fracture porosity occluded by Type C cement (18' SOT #1)
(D) Borings (Bo) cross cutting the sedimentary fabric of the Cayman Formation, note that the borings are partially filled with marine (mudstone) cavity filling sediment (MCf) (56' 4" SOT #2)
(E) Micritic sediment (Mc) partially filling a cavity (63' SOT #1)
(F) Clay sediment (CS) partially filling cavity (10' SOT #2)

primary porosity whereas dissolution created extensive secondary porosity. Dissolution can be so pronounced that areas of 'diagenetic grainstone' have been created through removal of the matrix and partial removal of the cements.

5.2.8 *Meteroic Cements*

Four types of meteoric cement are present in the Cayman Formation at Tarpon Springs Estates.

5.2.8a *Type A cement*

Three forms of Type A cement (types A1 - A3) line primary and secondary cavities in the formation. The boundary between the finely crystalline dolomite of the matrix and the cement is always sharp (Figure 5.6A). Cavities are lined with a single form of Type A cement and the temporal relationship between these cements cannot be discerned.

Type A1 cement is composed of isopachous, cloudy, euhedral to subhedral dolomite crystals that are 10 - 50 µm long with rare crystals greater than 80 µm long (Figure 5.6B and 5.6C). This is the dominant cement in the Cayman Formation of the study area (Figures 5.2 - 5.4). The cloudy nature of Type A1 may be due to the inclusion of precursor calcite. This cement may represent a recrystallized meteoric calcite cement. Type A1 cement is similar to the Type 1 cement recognized in the Cayman Formation of the Safe Haven area (Wignall, 1995).

Type A2 cement consists of zoned dolomite crystals comparable in size to Type A1 cement. This isopachous cement commonly consists of a cloudy core encased by a clear zone of dolomite (Figure 5.6D and 5.6E). This cement has a random distribution in the Cayman Formation of the study area (Figures 5.2 - 5.4). Type A2 zoned cement crystals may represent a distinct phase of cement precipitation or possibly a secondary phase of dolomite precipitation on pre-existing Type A1 cement. Type A2 cement is similar to the first generation, Type 2 cement of Jones *et al.* (1984), the cements described by Ng (1990), and the Type 3 cement of Wignall (1995).

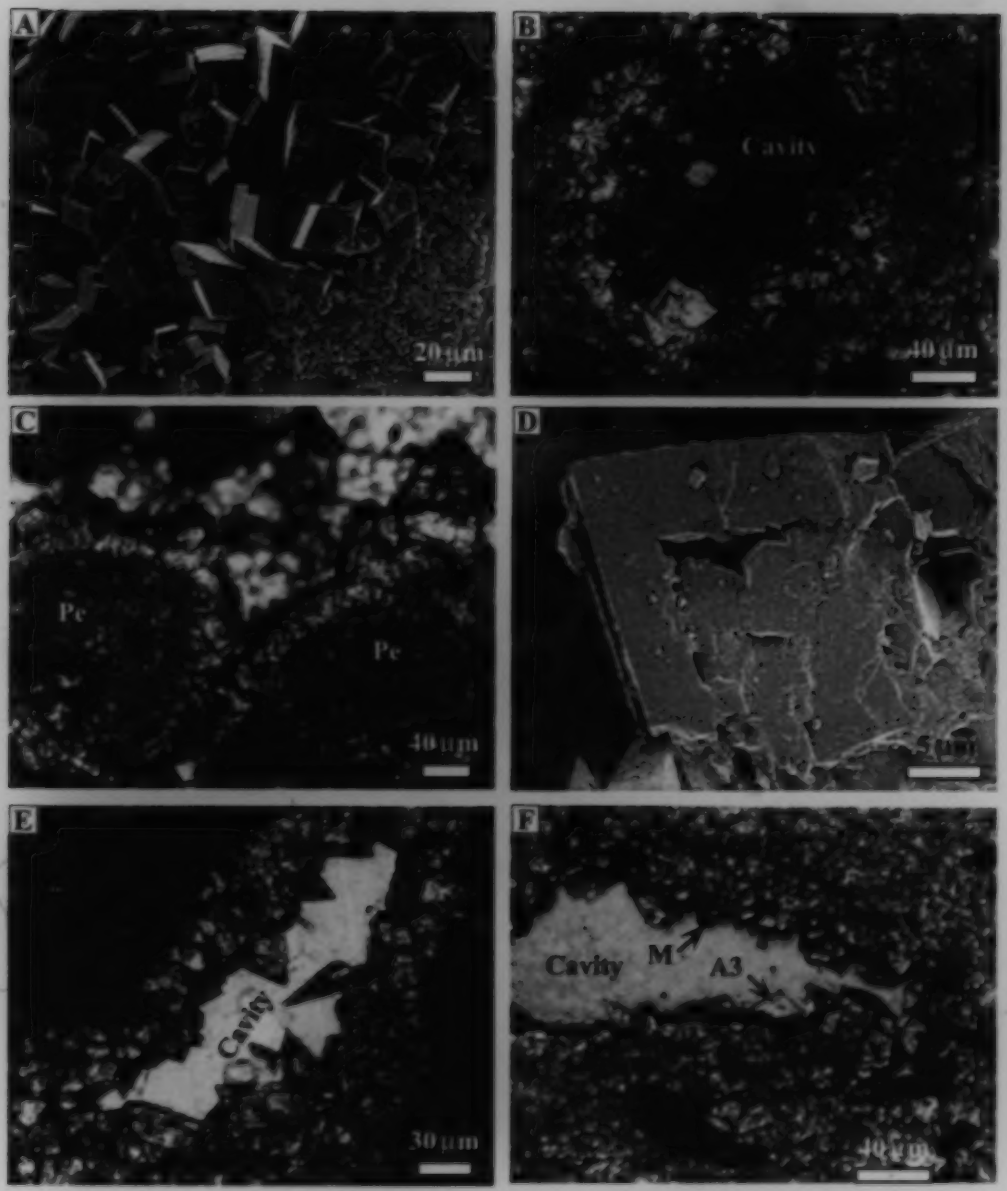

Figure 5.6: SEM images and photomicrographs of cements in the Cayman Formation

(A) SEM image of pore lining dolomite cement and Type 1 matrix dolomite (18'6" SOT#3)
(B) Type A1 meteoric cement lining a cavity (54' SOT #3)
(C) Type A1 meteoric cement rooted on peloids (Pe) (43' SOT#3)
(D) SEM image ofzoned dolomite crystal of Type A2 meteoric cement (92' SOT #1)
(E) Type A2 meteoric dolomite cement lining a cavity (12' SOT #3)
(F) Type A3 meteoric cement(A3) rooted on top of micritic cement (M) (5' SOT #1)

Type A3 cement is composed of limpid (inclusion-free) euhedral - subhedral dolomite crystals. These crystals, varying in length from 15 - 80 µm, have smooth faces and sharply terminated boundaries. These crystals may be rooted on matrix dolomites forming an isopachous lining or they may be rooted on other cements (Figure 5.6F). This indicates multiple (at least two) phases of limpid dolomite cementation or that precipitation of limpid dolomite cement took place late in the diagenetic history of the Cayman Formation. The limpid dolomite cement crystals rooted on Type B cements are smaller (15 - 25 µm long) in comparison to those rooted on matrix dolomites suggesting that two phases of limpid dolomite are present. Type A3 cement, which is randomly distributed throughout the study area (Figures 5.2 - 5.4) is similar to the first generation, Type 1 cement of Jones *et al.* (1984) and the clear, euhedral dolomite cement described by Ng (1990).

5.2.8b *Type B cement*

Type B cement in the Cayman Formation of the Tarpon Springs area is composed of banded dolomite and calcite cement (Figure 5.7A). These alternating bands are less than 10 µm thick, of uniform thickness, and are laterally continuous from crystal to crystal following the outlines of preceeding crystals (*cf.* Ng, 1990). Isopachous pore lining banded cement is rooted on matrix dolomites or on Type A cements and therefore postdates precipitation of Type A cement in the study area. These banded cements typically consist of a single band of dolomite followed by a single band of calcite. Multiple banding is restricted to the peripheral ridge (SOT #3). Precipitation of Type B cement is attributed to recurring changes in pore water chemistry (Jones *et al.*, 1984).

The distribution of this cement is variable in the study area, however it is most common in well SOT #3 with rare examples in wells SOT #2 and SOT #3 (Figures 5.2 - 5.4). This cement is similar to the (first generation) Type 3 cement of Jones *et al.* (1984).

5.2.8c *Type C cement*

Type C cement is composed of various types of spar calcite cement that may represent multiple generations of cementation. The relationship between these calcite cements is complex and cannot be determined with any certainty. All of these blocky calcite cements postdate Type A and Type B meteoric cements. The most common cement is composed of micro - mesocrystalline (50 - 800 µm long) subhedral calcite crystals with nonplanar boundaries. Type C cement is rooted on Type I matrix dolomite, Type A or Type B cement. This cement, which commonly occludes small pores or is found lining larger pores (Figure 5.7B), is similar to the second generation cement described by Jones *et al.* (1984) and fourth generation cement of Wignall (1995).

In the study area this cement is found throughout all three wells but is relatively rare below a depth of 15.3 m (Figures 5.2 - 5.4). Associated with the micro - mesocrystalline sparry calcite cement in the study area, is a drusy calcite cement. This drusy cement is rare in the Cayman Formation of the study area; however, it is similar to the drusy calcite cement described from the the Safe Haven area (Wignall, 1995).

5.2.8d *Type D cement*

Type D cement consists of banded dolomite and calcite speleothems. Band thickness is highly variable ranging from bands 15 µm to 0.1 mm thick. This cement is rooted on matrix dolomite, Type A cements, or in rare examples on Type C cement. This cement has a similar fabric to the second generation meteoric banded cements but formed later in the diagenetic history of the Cayman Formation in the study area.

Type D cement was precipitated in the vadose zone and is equivalent to the third generation cements described by Jones *et al.* (1984). This form of cement is restricted to the uppermost 5.5 m of the Cayman Formation in well SOT #3 (Figure 5.2).

5.2.8e *Additional cements*

Two additional rare forms of cement are present in the Cayman Formation at Tarpon Springs Estates. The relationship between these cements and the other cements in the study area cannot be determined. An isopachous bladed dolomite cement consisting of laths 3 -7 μm wide and approximately 10 μm long is present at 3.7 m asl in SOT #3. These dolomite crystals possess cloudy cores and inclusions. This cement appears to have formed from the replacement (dolomitization) of a precursor fibrous or bladed metastable cement.

A micritic dolomite cement (crystals < 4 μm long) is present in some cavities in the study area. This rare cement has a variable distribution throughout the three wells in the study area (Figure 5.2 - 5.4). Micritic cement may be associated with micritic cavity filling sediment, however it is differentiated from the later because it lines voids.

5.2.9 *Cavity Filling Sediments*

Four types of cavity filling sediment are present in the Cayman Formation at Tarpon Springs Estates. The first type of cavity filling sediment consists of dolomitized mudstone and rare wackestone. The presence of fragmented coralline algae and/or foraminifera in these sediments suggests a marine origin. Most borings and some cavities in the Cayman Formation of the study area are filled with marine sediment (Figure 5.6D and 5.6E). This type of cavity filling sediment rarely occludes these cavities.

Marine cavity filling sediment is distributed throughout the Cayman Formation in the study area (Figures 5.2 - 5.4). This cavity filling sediment is similar to that described from the Safe Haven area (Wignall, 1995).

Some cavities contain banded, fine grained, white to multicoloured, caymanite (*cf.* Jones, 1984). Caymanite is composed of surface derived sediment from ponds and swamps that is washed down into place (Lockhart, 1986). Emplacement of caymanite in the study area commonly postdates precipitation of dolomite cement although some

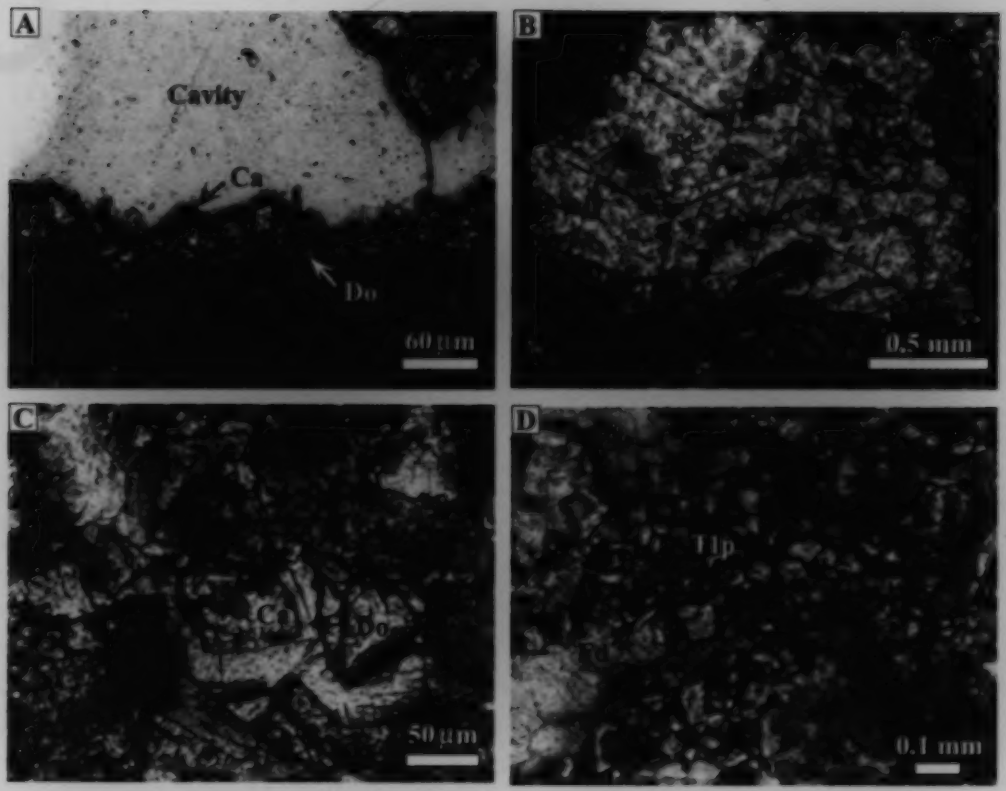

Figure 5.7 : Photomicrographs of the Cayman Formation

(A) Type B meteoric cement consisting of dolomite (Do) - calcite (Ca) couplet (43' SOT #3)
(B) Single crystal of Type C meteoric calcite cement (TC), note cleavage planes (18' SOT #1)
(C) Type I poikilotopic calcite - dolomite fabric, note calcite filling and surrounding dolomite rhomb (23' SOT #1)
(D) Type I poikilotopic calcite - dolomite fabric (T1p), note fragmented remnants of hollow dolomite rhombs (Fd) (5' SOT #1)

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cavities are directly lined with caymanite. All caymanite present in the study area is dolomitized. Caymanite is present in all three wells of the study area but is more restricted in distribution relative to the marine cavity filling sediment.

A fine grained red material, interpreted as red clay, is present in some cavities (Figure 5.5F). Emplacement of this calcareous material postdates dolomitization but appears to predate Type C meteoric cement in the study area. Red clay in the Cayman

Formation appears to be detrital in origin because it is found close to the surface (< 3 m bsl) in wells SOT #1 and SOT #2 (Figures 5.2 - 5.4). This cavity filling sediment is similar to that described elsewhere in the Cayman Formation by Jones *et al.* (1984).

A fourth type of cavity filling sediment found in the study area consists of a dense, black, fine grained material. The black colouration of this fine grained sediment is attributed to the presence of manganese. This sediment is derived from the terra rossa and swamps that have formed on the surface of the Cayman Formation at various times (Jones, 1992b). These manganese precipitates are akin to the structureless manganese coatings described elsewhere on the island by Jones (1992b). This sediment is restricted to wells SOT #1 and SOT #3 (Figures 5.2 and 5.4) and where present, partially fills cavities or is situated on top of the marine mudstone and wackestone cavity filling sediment. The undolomitized nature of this sediment indicates that it postdates dolomitization. This sediment is not found associated with the red clay cavity filling sediment. The genetic relationship between these two sediments is unclear.

5.2.10 *Dolomite Dissolution*

Petrographic evidence from the study area suggests that some dolostone has been subjected to dissolution. Some cavities in the Cayman Formation have Type A cement preferentially dissolved on their floors and adjacent walls. This pattern of dissolution indicates that cavities, at some times, were partially filled with agressive pore fluids. If these pores were completely filled than the entire pore would exhibit evidence of dissolution. Partially filled pores are characteristic of the vadose zone. Vadose fluids are commonly strongly aggressive (undersaturated) with respect to most carbonate mineral species. This aggressiveness is attributed to the high P_{CO_2} levels in vadose waters derived primarily from soils. Preferential dolomite dissolution in the study area is found between 18.3 m and 36.6 m bsl (60 - 120 ft) in wells SOT #1 and SOT #2 (Figures 5.2 and 5.3).

Dissolution has also affected the matrix dolomites. Type I matrix dolomite commonly contains solid relicts of presursor calcite. In some areas these presumably unstable cores (aragonite or high-Mg calcite) have been leached (Jones *et al.*, 1989). This dissolution results in the formation of hollow dolomite rhombs (Figure 5.1A).

5.2.11 *Poikilotopic Calcite - Dolomite Fabrics*

Some dolomite rhombs in the Cayman Formation are encased by large calcite crystals whereas others with leached cores have been subsequently filled and encased by calcite (Figure 5.7C and 5.7D). This fabric results from the replacement of dolomite by calcite. Development of this fabric on Grand Cayman proceeded through a series of time separated processes (Jones *et al.*, 1989). The resultant fabric created from these distinct processes was termed poikilotopic calcite-dolomite fabric by Jones *et al.* (1989).

Two types of poikilotopic calcite-dolomite fabrics are found in the study area. The first type encases and/or fills leached cores of Type A meteoric dolomite cements and is therefore restricted to cavities in the Cayman Formation. This fabric is similar to the Type I poikilotopic calcite-dolomite fabric described by Jones *et al.* (1989). Formation of this fabric involved time separated processes - precipitation of first generation cements, preferential dissolution of unstable cores in zoned crystals and precipitation of calcite. These processes formed in response to a progressive freshening of pore fluids (Pleydell, 1987; Jones *et al.*, 1989).

The second type of poikilotopic calcite-dolomite fabric found in the study area is located in the dolomitic matrix around molds and vugs (Figure 5.8B) that were permeability conduits for fluid movement (Ng, 1990). Fluids moving through these conduits preferentially dissolved dolomite and precipitated calcite forming a chalky reaction rim of poikilotopic calcite-dolomite. (Wignall, 1995). This fabric is similar to the Type II poikilotopic calcite-dolomite fabric described by Jones *et al.* (1989).

5.2.12 *Calcrete*

Calcrete fabrics, consisting of rhizoliths and laminated crusts (Figure 5.8C) are restricted to the subsurface at Tarpon Springs Estates. Most rhizoliths have been filled with calcitic sediment subsequent to decay and removal of the root. Laminated crusts are relatively rare and are restricted to well SOT #3. These crusts are thin (< 1 cm) with individual laminations 0.5 - 2 mm thick. Calcrete fabrics are most abundant in well SOT #3. This abundance is attributed to the fact that strata composing the uppermost part of the peripheral ridge (6 - 10 m asl) has been subaerially exposed since the Late Pliocene.

5.2.13 *Terra Rossa*

Terra rossa in the Tarpon Springs area consists of iron rich, fine grained, calcitic, soil derived material that fills near surface cavities and/or rhizoliths. This sediment contains 0.2 - 2.5 mm long, iron rich, subangular to rounded glaebules and contains angular clasts of Cayman dolostone (Figure 5.8C). Glaebules are commonly enveloped by a circumgranular calcite cement.

Terra rossa is present in all three wells drilled in the study area. This sediment is rarely found below a depth of 10 m bsl (Figure 5.2 - 5.4). The calcitic composition, and presence of dolostone clasts derived from the Cayman Formation indicate that terra rossa development post-dated dolomitization fabrics.

5.2.14 *Karst*

Karstification of the Cayman Formation at Tarpon Springs Estates is restricted to surface features; caves and/or caverns were not encountered during drilling. Surficial karst in the study area is restricted to exposures of the Cayman Formation along the peripheral ridge. There, the present day surface is characterized by black to dark grey coloured pinnacles. These rectangular to circular, conical forms (Sweeting, 1972) are

10 - 40 cm high with a diameter of 20 - 30 cm at the base. These features represent the remnants of intense dissolution that took place on a local scale (Squair, 1988). The blackened appearance of pinnacles and exposures of the Cayman Formation on Grand Cayman is a feature of phytokarst (*cf.* Folk *et al*, 1973). The black colour on the surface of the rocks is due to the presence of decaying organic material (Squair, 1988). These phytokarsted pinnacles are dominated by additional small scale solution features.

Root lapies (*cf.* Schneider, 1976), 1 - 10 cm in diameter and 2 - 30 cm long, are present in most pinnacles. In addition small hemispherical rain pits commonly, less than 2 cm wide and 2 cm deep, are developed on pinnacles.

5.3 Paragenetic History of the Cayman Formation

Diagenesis encompasses all of the post-depositional processes (excluding metamorphism) that affect a carbonate sediment (Tucker and Wright, 1990). The paragenetic history of the Cayman Formation on Grand Cayman is complex (Jones *et al*, 1984; Pleydell, 1987; Pleydell *et al*, 1990, Ng, 1990; Wignall, 1995). As yet, integration of stratigraphic, sedimentological, and diagenetic information has not provided a definitive interpretation of the paragenetic history of the Cayman Formation (Ng, 1990). Similarly, the paragenetic history of the Cayman Formation at Tarpon Springs Estates is complex.

Sediment that ultimately formed the Cayman Formation was modified by early marine diagenetic processes. The presence of hardground surfaces in the Cayman Formation attest to periods of early marine cementation.

Sea level during the Messinian lowstand was at least 40.6 m below present day sea level (Jones and Hunter, 1994b). As a result, the Cayman Formation was subaerially exposed. This environmental change led to the establishment of meteoric diagenetic processes which exposed the Cayman Formation to influxes of fresh and mixed groundwaters (Wignall, 1995). This exposure event marks a change in environmental

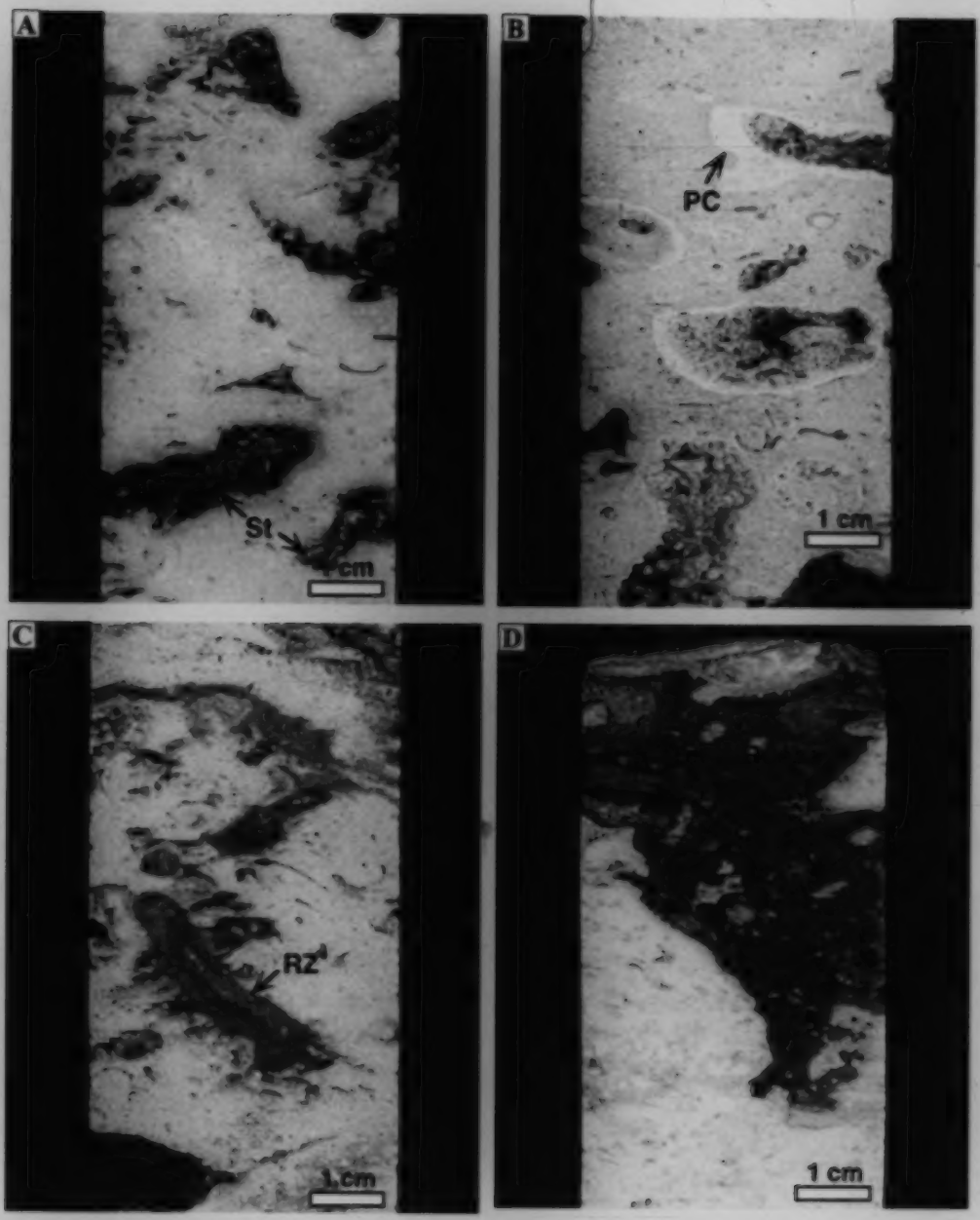

Figure 5.8: Core photographs of the Cayman Formation

(A) Molds of fragmented *Stylophora* (St) (36' SOT #3)

(B) Poikilotopic calcite-dolomite (PC) rimming *Stylophora* mold (36'8" SOT #1)

(C) Rhizoliths (RZ) developed in the Cayman Formation (10'10" SOT#2)

(D) Terra rossa, note angular clasts (AC) of Cayman dolostone (12'6" SOT #3)

conditions and diagenetic regimes from a marine to terrestrial setting (Jones and Hunter, 1994a; Wignall, 1995).

The preservation of secondary moldic porosity in the Cayman Formation indicates that the sediment must have been well lithified prior to the onset of meteoric dissolution. The preferential dissolution of the aragonite allochems indicates that meteoric fluids were undersaturated with respect to aragonite. Extensive secondary porosity was created in areas where corals, bivalves, and gastropods were abundant. By comparison, allochems originally composed of Mg calcite underwent varying degrees of dissolution. Coralline red algae commonly displays microvuggy dissolutional voids whereas *Amphistegina* was completely dissolved (biomoldic porosity), partially dissolved (displays microvuggy dissolutional voids) or unaffected. Meteoric dissolution presumably took place prior to stabilization/replacement of aragonite and high-Mg calcite to calcite and/or dolomite. Meteoric dissolution of aragonite that occurred during the Messinian provided $CaCO_3$ which appears to have been precipitated as a meteoric calcite cement in the study area. Type A1 meteoric dolomite cement may have subsequently replaced this presumed meteoric calcite cement.

Secondary porosity developed in the Cayman Formation has commonly been reduced by cements and/or cavity filling sediment. These diagenetic fabrics rarely occlude secondary porosity. Most of the cavities in the study area are lined by cement (Type A, B, or C). Some pores, however, do not contain pore lining cement. Secondary porosity in these pores is preserved or may be reduced due to the presence of cavity filling sediment. Cavity filling sediment includes marine cavity filling sediment and caymanite, both of which are dolomitized suggesting that deposition took place prior to dolomitization.

Deposition of caymanite appears to have taken place after deposition of marine cavity filling sediment in the study area. The latter is present in cavities and borings

whereas caymanite is restricted to dissolution cavities. Wignall (1995) concluded that the caymanite in the Safe Haven area may have been derived from marine or non-marine sediment. The origin of caymanite in the Tarpon Springs area, which is dominated by dolomitized mudstone is also ambiguous. The lack of marine allochems argues against a marine origin; however, the micritic sediment could have a marine origin.

Dolomitization appears to have taken place relatively early in the diagenetic history of the Cayman Formation. Mimic replacement of high-Mg calcite allochems in the Cayman Formation may indicate that dolomitization took place prior to the stabilization of aragonite and high-Mg calcite allochems (Pleydell, 1987; Pleydell *et al.*, 1990). Experimental work by Bullen and Sibley (1984) showed that mimic replacement of high-Mg calcite allochems can take place after stabilization to low-Mg calcite. Mimic replacement of high-Mg calcite allochems does not appear to have any bearing on the timing of dolomitization.

Replacement of meteoric calcite cement and direct precipitation of meteoric dolomite cements appears to have taken place prior to dolomitization of caymanite. A cavity at 51 m bsl in SOT #2 is lined with Type A1 meteoric cement (Figure 5.9). The cloudy nature of Type A1 cement is attributed to the inclusion of precursor calcite which suggests that the cement may be a replacement fabric (*cf.* Budd, 1997). In addition, the euhedral cement crystals indicate that crystal growth was unimpeded. The euhedral nature of this Type A1 cement indicates that replacement of the meteoric calcite cement took place prior to the emplacement of caymanite. The presence of caymanite emplaced in the cavity prior to cement replacement would have impeded crystal growth thereby preventing the development of the euhedral crystals. The emplacement of caymanite in this cavity presumably took place after cementation when sediment ladden waters moving down through the vadose zone reached the phreatic zone. The position of this cavity at 51 m bsl is therefore an approximation of the position of the phreatic zone at the time of deposition. A phreatic zone at 51 m bsl could only have been established towards

the end of regression or during the initial stages of transgression. Development of Type A1 cement in this cavity therefore took place during late regression or early stages of the transgression.

In contrast to Type A1 cement, Types A2 and A3 meteoric dolomite cements in the Cayman Formation are the result of direct precipitation. These void lining crystals are commonly euhedral in shape with planar boundaries between adjacent crystals. Their restricted distribution and morphology indicates direct precipitation (Jones *et al.*, 1984).

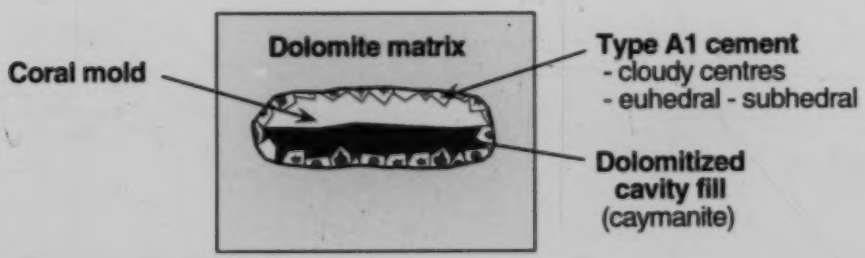

Figure 5.9: Cement and internal sediment in a cavity in the Cayman Formation (SOT #2 at 51 m bsl).

Type B cements in the study area reflect precipitation from constantly evolving pore fluids (Jones *et al.*, 1984). The random distribution (lateral and vertical) of this cement in the study area indicates precipitation from isolated, laterally restricted water lenses. In rare cases, Type B cement is rooted on Type A cement, indicating that the former postdated the latter. The alternating dolomite - calcite banding of Type B cement is a primary feature. The presence of dolomitized cavity filling sediment on top of Type B cement in the study area indicates that precipitation of Type B cement predates pervasive dolomitization of the Cayman Formation at Tarpon Springs Estates.

Type I and Type II matrix dolomite in the Cayman Formation indicate two separate phases of dolomitization. The variable distribution of Type II matrix dolomite indicates

that the second phase of dolomitization was not pervasive. This later phase of dolomitization resulted in the partial recrystallization of Type I matrix dolomite. The presence of Type II matrix dolomite at depths in excess of 50 m indicates that these fluids were present at a considerable depth in the study area. The initial phase of matrix dolomitization resulted in the formation of Type I matrix dolomite. In addition, this form of dolomite also replaced most Mg calcite allochems and commonly preserved their internal structure (mimic replacement and non-mimic fabric preserving texture). By comparison, the second phase of dolomitization resulted in the development of fabric destructive, Type II matrix dolomites.

Calcite cements in the Cayman Formation of the study area consist of coarse, sparry crystals. This Type C meteoric cement probably precipitated slowly from freshwater with low concentrations of calcium (e.g., Folk and Land, 1975; Kaldi and Gidman, 1982). Folk and Land (1975) suggested that precipitation of this form of calcite takes place in pores completely filled with water in the freshwater phreatic environment. Sparry calcite cement in the Cayman Formation elsewhere on Grand Cayman appears to be a recent cement associated with present day hydrochemical conditions (Ng, 1990).

Periods of dissolution have taken place throughout the diagenetic history of the Cayman Formation at Tarpon Springs Estates. One such period of dissolution is evident in wells SOT #2 and SOT #3 in the stratigraphic interval between 18.3 - 36.6 m bsl. Dissolution in this interval has affected allochems and cements. Type A meteoric cement has been partially dissolved in some cavities, indicating that dissolution postdated precipitation of dolomite cements. This zone of dissolution is correlatable between wells SOT #1 and SOT #2 in the study area and is consistent with a zone of dissolution in the Safe Haven area at 40 m bsl. This zone of dissolution appears to be a regional feature and may in fact represent a zone of mixing corrosion associated with a paleometeoric water lens (Wignall, 1995).

Meteoric diagenetic alteration at Tarpon Springs Estates is not restricted to the

subsurface because exposures of the Cayman Formation have been affected by several periods of subareal exposure and meteoric diagenesis. Karst development is restricted to surface exposures of the Cayman Formation. Karstification of surface exposures is a present day diagenetic process. The black colouration characteristic of jagged, pinnacled karsted surfaces is not evident in core recovered from Tarpon Springs. Paleokarst and surficial features associated with the Cayman Unconformity, if developed in the study area were not encountered or were removed during periods of subareal exposure in the Late Miocene and Middle Pliocene.

Calcrete and terra rossa composed of calcitic sediment and cement, are meteoric diagenetic products developed in the study area. These products, restricted to the subsurface, are post-dolomitization features that developed during Pleistocene or modern times. Calcrete and/or terra rossa developed in association with earlier periods of exposure in the Late Miocene and Late Pliocene is not preserved in the study area. The absence of these diagenetic fabrics and products characteristic of exposure surfaces in the study area suggests that they were removed. This removal may have been facilitated by marine erosion associated sea level transgressions (Early Pliocene and/or Pleistocene) or possibly by meteoric diagenetic processes associated with a period of subaerial exposure (Late Pliocene).

5.4 Dolomitization of the Cayman Formation

Dolomitization of the Bluff Group on Grand Cayman has been examined in many studies (Jones *et al.*, 1984; Pleydell, 1987; Pleydell *et al.*, 1990; Ng, 1990; Wignall, 1995). Interpretation of the previously available data has failed to provide an unequivocal answer for the number of dolomitizing events, the timing of dolomitization, and the process(es) responsible. Dolomitization may therefore be the result of a single phase that took place late in the diagenetic history of the Bluff Group (Pleydell, 1987; Jones, 1989; Pleydell *et al.*, 1990) or the result of multiple phases (Ng, 1990; Wignall,

1995; Budd, 1997). The argument for a single all encompassing phase of dolomitization is based primarily on the petrographic and isotopic homogeneity of the dolostones in the Bluff Group.

Petrographic homogeneity of diagenetic fabrics in the Cayman and Pedro Castle formations has been used as evidence to support the idea of a single phase of dolomitization. The Cayman Formation was exposed to meteoric diagenetic processes (dissolution and cementation) during the Messinian lowstand. These processes diagenetically altered the depositional fabric of the Cayman Formation. In addition the Cayman Formation experienced a second phase of meteoric diagenesis in the Late Pliocene following deposition of the Pedro Castle Formation. In order to achieve petrographic homogeneity in the Cayman and Pedro Castle formations from a single phase of dolomitization, the carbonate precursors of the two formations would have to be altered to the same fabric. This pattern of alteration is unlikely (Ng, 1990).

Two types of matrix dolomite (types I and II) in the Cayman Formation at Tarpon Springs Estates may indicate two separate phases of dolomitization. Type II matrix dolomite crystals are larger in size relative to Type I and commonly contain palimpsest remnants of Type I matrix dolomite (Wignall, 1995). This evidence indicates that Type II matrix dolomite formed later and involved some recrystallization of Type I matrix dolomite.

$^{87}Sr/^{86}Sr$ isotope ratios of the Cayman and Pedro Castle formations have been used to suggest that dolomitization took place 2 - 5 Ma (Pleydell, 1987; Pleydell *et al.*, 1990). Similarity between the isotope ratios derived from dolostones in the two formations has been attributed to a single phase of dolomitization (Pleydell, 1987; Pleydell *et al.*, 1990). $^{87}Sr/^{86}Sr$ isotope ratios can be reset by recrystallization (Machel and Mountjoy, 1986) or may reflect fluids that stabilized previously formed dolomite (Land, 1985). Diagenetic overprinting of the $^{87}Sr/^{86}Sr$ isotope ratio of the previously formed dolomites of the Cayman Formation could account for the uniform $^{87}Sr/^{86}Sr$ isotope ratio of the Bluff

Group (Ng, 1990).

Diagenetic fabrics developed in the Cayman Formation appear to be the result of two phases of dolomitization (Ng, 1990; Wignall, 1995). Dolomitization of the Pedro Castle Formation is patchy whereas dolomitization of the Cayman Formation is pervasive. A single phase of dolomitization that postdated deposition of Pliocene strata would have affected the Cayman and Pedro Castle formations alike. Thus, it seems unlikely that a single phase of dolomitization would affect the entire Cayman Formation while only affecting isolated areas of the Pedro Castle Formation (Wignall, 1995).

The timing of these dolomitization events is open to debate. Dolomitization appears to have taken place at various times in the diagenetic history of the Cayman Formation. The development and precipitation of dolomite cements took place early in the diagenetic history of the Cayman Formation. These dolomite cements postdate aragonite dissolution and precipitation of meteoric calcite cements. Meteoric dissolution of aragonite and precipitation of calcite cements would have taken place during the regression associated with the Messinian lowstand. It is therefore probable that the formation of meteoric dolomite cements took place during the subsequent Lower Pliocene transgression.

Dolomitization of the matrix may be contemporaneous or may post date the formation of dolomite cements. Petrographical and geochemical data indicate that the formation of dolomite cements and pervasive dolomitization of matrix are time separate events. The relationship between meteoric dolomite cements and caymanite indicates that precipitation of Type A cements took place during the Messinian. In contrast the $^{87}Sr/^{86}Sr$ isotopic ratios indicate that one phase of dolomitization took place during the Pliocene, some 2 - 5 million years ago. This late phase of dolomitization has presumably overprinted and reset the $^{87}Sr/^{86}Sr$ isotopic ratio of the earlier phase(s). The contrasting evidence indicates that meteoric dolomite cements and matrix dolomitization are unrelated and therefore may have formed from different parent fluids.

Grand Cayman serves as a natural laboratory for studying dolomitization. The island's isolated setting and the lack of a burial phase precludes many of the dolomitization models. Two dolomitization models appear feasible; dolomitization in a mixed marine and freshwater (mixing zone dolomitization) environment and dolomitization mediated by seawater. A third model, dolomitization from hypersaline waters is unlikely because no trace of evaporites have been found in the Bluff Group (Pleydell *et al.*, 1990).

Mixed meteoric-marine waters have been cited in the formation of post depositional replacement dolomites (Badiozamani, 1973; Land, 1973; Sibley, 1982; Ward and Halley, 1985; Humphrey, 1988). Dolomitization from mixed meteoric-marine waters can form pervasive or partially dolomitized successions. The replacive dolomites of the Bluff Group on Grand Cayman have been attributed to mixed meteoric-marine waters (Jones *et al.*, 1984; Ng, 1990). Dolomite cements present at Tarpon Springs Estates are similar to those of Jones *et al.* (1984) and Ng (1990) and are interpreted to have formed in a mixed meteoric-marine water environment. Limpid dolomite is common as an isopachous void lining cement (Type A3) in the study area. This form of dolomite represents precipitation from mixed meteoric-marine water (Folk and Land, 1975) with a low Mg/Ca ratio. In addition the random distribution (lateral and vertical) of cements in the study area suggests that the dolomitizing fluids were discontinuous and localized. The distribution of dolomite cements in the study area is the result of precipitation from a mixed meteoric-marine water lens which varied laterally and vertically. Partial or pervasive dolomitization of the matrix could have taken place concurrently with precipitation of the meteoric dolomite cements from the same parent fluid. Dolomite cementation and pervasive dolomitization, however, appear to be time separated processes and therefore may represent different parent fluids.

Seawater has been proposed as a potential dolomitizing fluid (Saller, 1984; Compton and Siever, 1986; Coniglio *et al.*, 1988) and has been deemed responsible for

dolomitizing the Bluff Group (Pleydell, 1987; Pleydell *et al.*, 1990). Based on $\delta^{18}O$ values of dolostones in the Bluff Group, Pleydell (1987) concluded that dolomitization took place in normal marine water. These isotope values, however, are inconclusive of dolomitization from normal marine water. Variability in the isotopic data (Figure 5.10B) for different mineral phases suggests a possible dolomitizing fluid composition ranging from 25% - 100% normal seawater salinity over a temperature range of 22 - 33 °C (Ng, 1990).

Limpid dolomite cements in the Bluff Group have varying $\delta^{18}O$ values, from +1.4 to +2.6‰ PDB (Figure 5.10A) with an average $\delta^{18}O$ value of +2.2‰ (Ng, 1990). The nature and distribution of meteoric dolomite cements in the study area indicates a mixed meteoric-marine water origin which is consistent with the isotopic data. In comparison, matrix dolomites of the Bluff Group have a narrow $\delta^{18}O$ range from +2.0 to +3.0‰ PDB (Figure 5.9A) with an average value of +2.5‰ (Ng, 1990). Type 1 matrix dolomite is pervasive in the Cayman Formation on Grand Cayman. The island wide distribution of matrix dolomite suggests the existence of a regionally extensive dolomitizing fluid. Dolomitization by normal marine water could account for the regional distribution of matrix dolomite and is consistent with the available $\delta^{18}O$ isotopic data. Dolomitic fabrics developed in the Cayman Formation at Tarpon Springs Estates could have formed in two different environments from two different fluids - mixed meteoric-marine water and normal marine water.

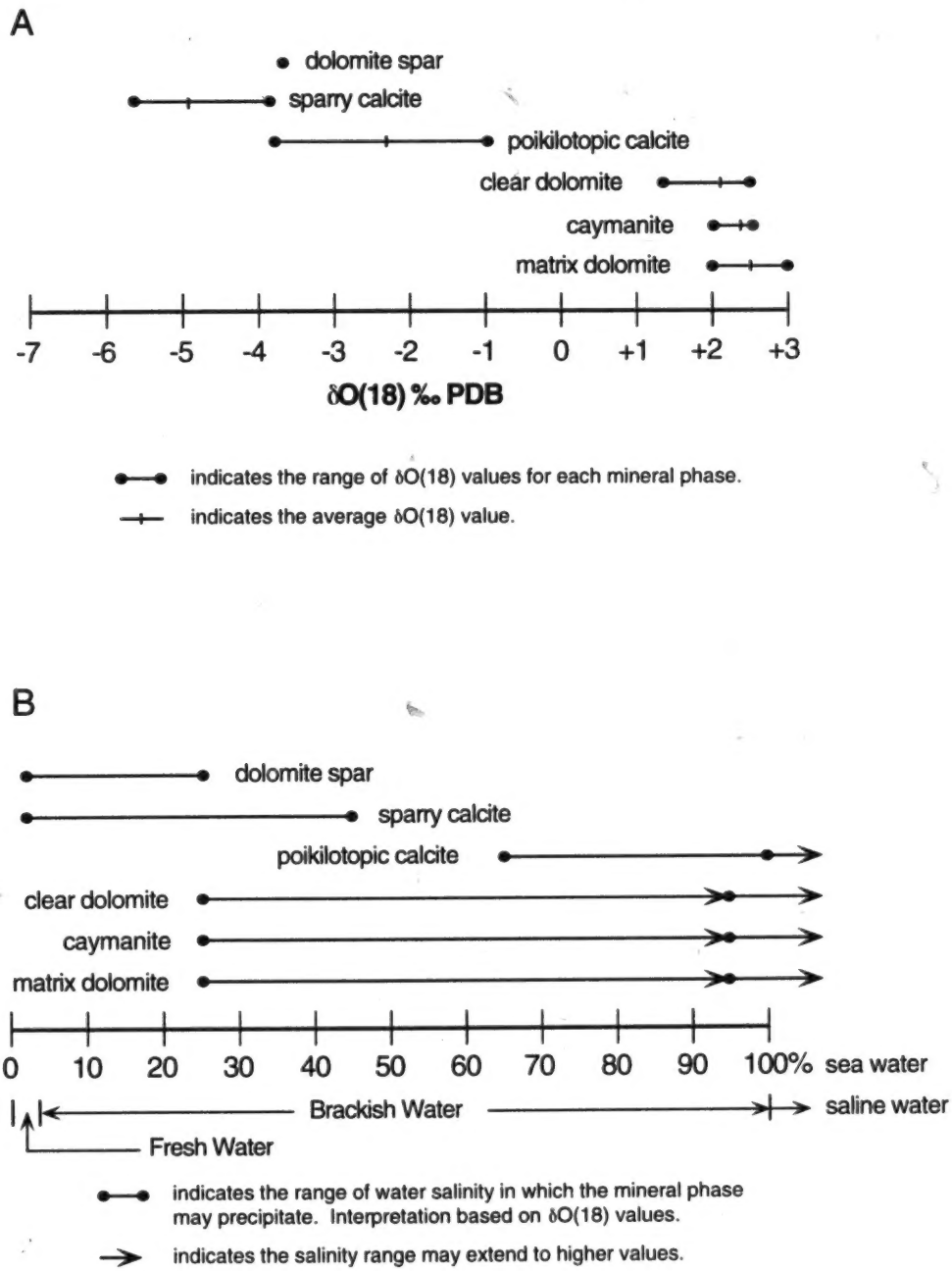
A
dolomite spar
sparry calcite
poikilotopic calcite
clear dolomite
caymanite
matrix dolomite
-7 -6 -5 -4 -3 -2 -1 0 +1 +2 +3
δO(18) ‰ PDB
indicates the range of δO(18) values for each mineral phase.
indicates the average δO(18) value.
B
dolomite spar
sparry calcite
poikilotopic calcite
clear dolomite
caymanite
matrix dolomite
0 10 20 30 40 50 60 70 80 90 100% sea water
Brackish Water
saline water
Fresh Water
indicates the range of water salinity in which the mineral phase may precipitate. Interpretation based on δO(18) values.
indicates the salinity range may extend to higher values.

Figure 5.10: Summary diagrams showing (A) the range ofδO(18) values for the various carbonate minerals present and (B) the range of water salinity in which these various carbonate minerals may precipitate (modified from Ng, 1990)

Chapter 6

The Cayman - Ironshore Unconformity

6.1 Introduction

The eustatic sea level fall associated with the Messinian lowstand exposed the Cayman Formation to meteoric diagenetic processes for approximately 1.5 million years. Subaerial diagenetic processes resulted in the development of a high relief (up to 40 m) surface on top of the Cayman Formation that is now known as the Cayman Unconformity (Jones and Hunter, 1994b). The most noticeable features of the Cayman Unconformity are the large western depression located directly under North Sound and a peripheral ridge (Figure 6.1). The Cayman Unconformity is topographically higher on the eastern half of Grand Cayman. The peripheral ridge attains elevations in excess of 10 m asl on the eastern half whereas the ridge on the western half of the island rarely attains elevations greater than 5 m asl (Figure 6.2).

The morphology and location of the peripheral ridge suggests that it may be a constructional feature such as a reef or sand dune that formed around the periphery of a bank (Jones and Hunter, 1994b). Analysis of core recovered from well SOT #3 and detailed sampling elsewhere on the island fails to provide evidence that would support such an origin. Thus, the topography on the Cayman Unconformity has been attributed to erosional processes (Jones and Hunter, 1994b).

Erosional features in the Cayman Formation are commonly associated with the Cayman Unconformity. Present day caves located beneath the peripheral ridge are elongate parallel to the trend of the ridge (Jones and Hunter, 1994b). A cave that was once evident in the south wall of Pedro Castle Quarry had an opening that extended upwards to the Cayman Unconformity. Unfortunately, successive years of quarrying has removed this feature. In addition to caves, paleosinkholes are common in the northeast

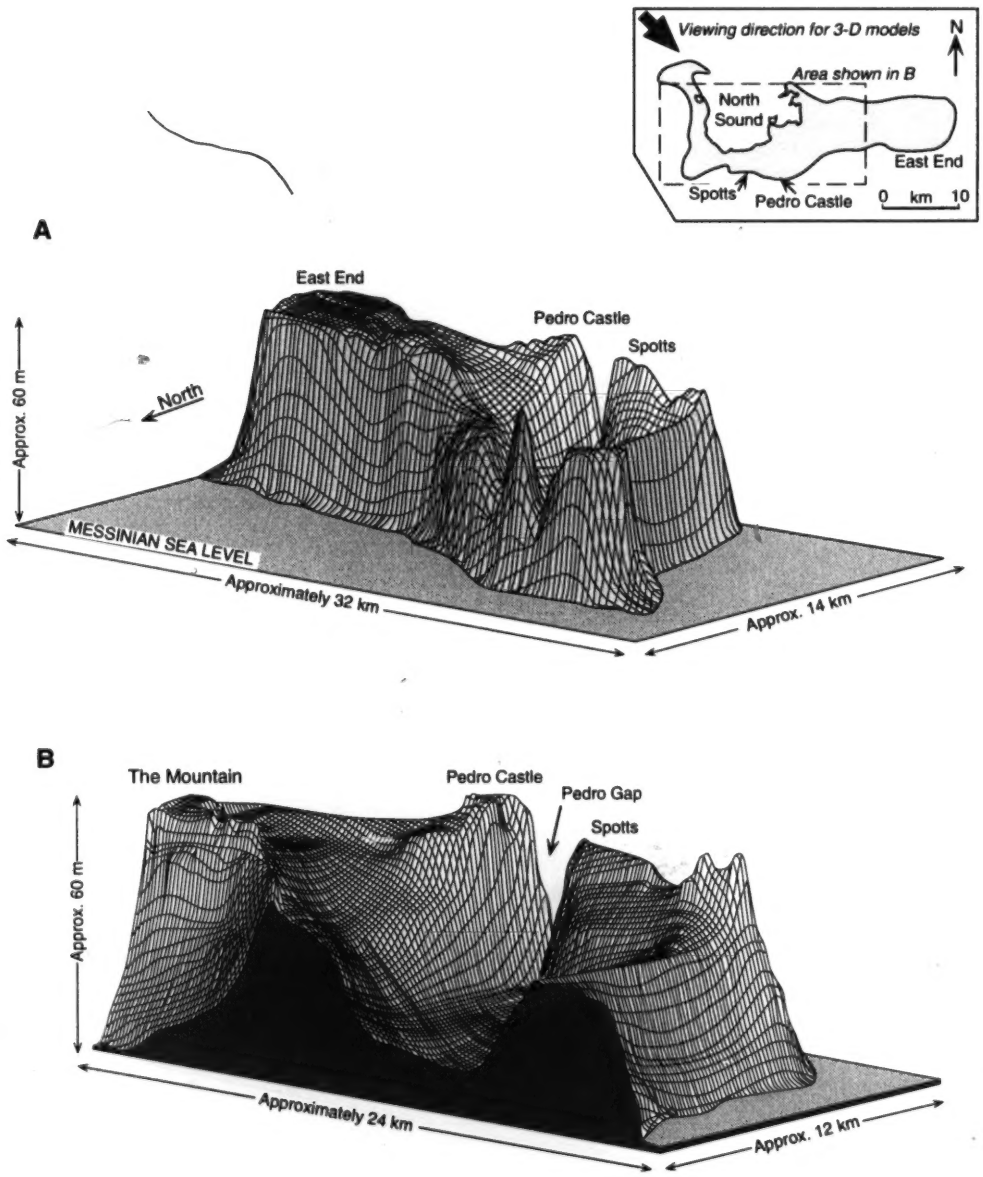

Figure 6.1: Conceptual three dimensional representation of the Cayman Unconformity. **A)** Topography developed on Grand Cayman by the end of the Messinian. **B)** Detailed model showing the topography on the Cayman Unconformity for the western half of Grand Cayman (modified from Jones and Hunter, 1994b).

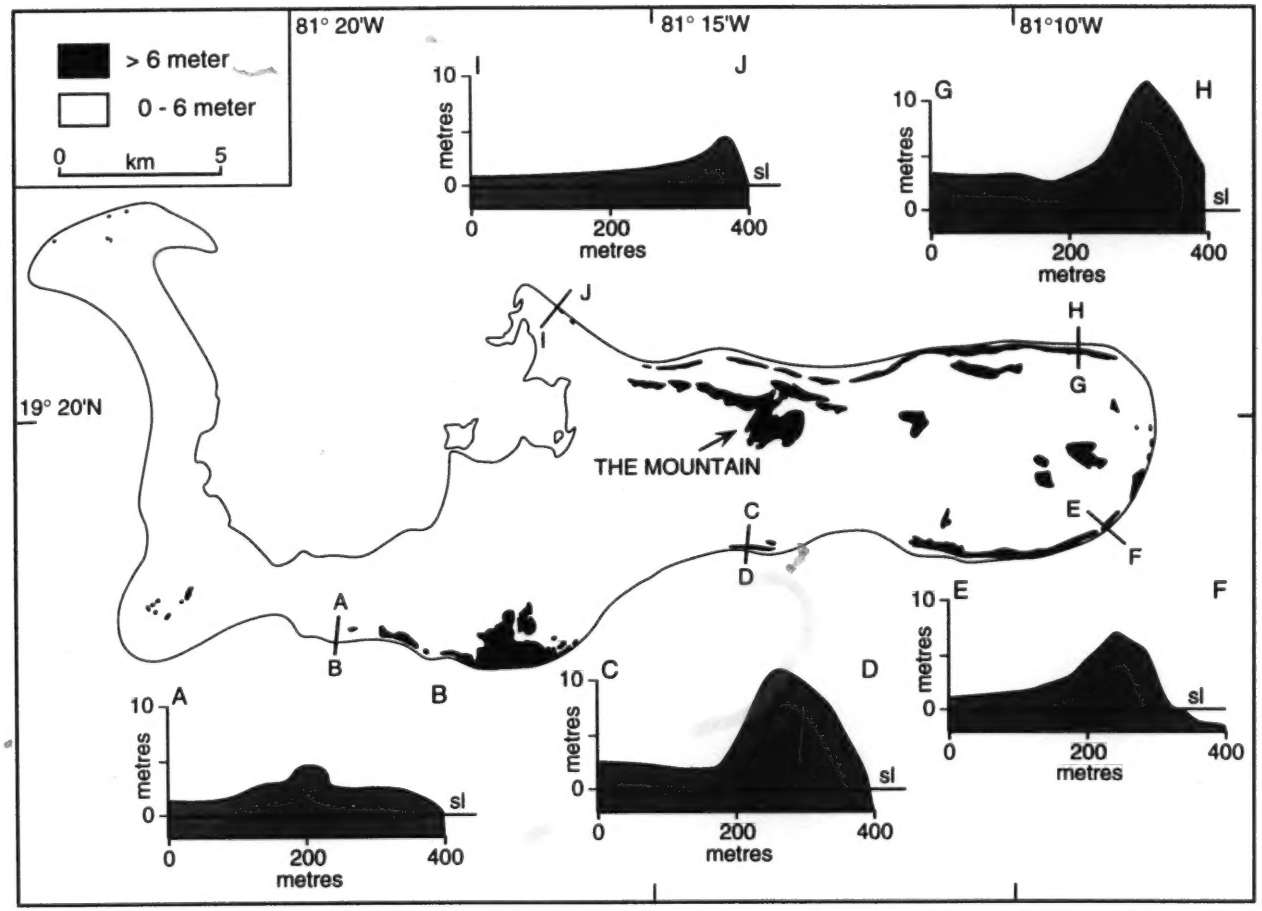

Figure 6.2: Topography of Grand Cayman and distribution of the exposed peripheral ridge on Grand Cayman (modified from Jones and Hunter, 1994b).

corner of Grand Cayman. Drilling has shown that these features are filled with the Pedro Castle Formation. Thus, the formation of these sinkholes took place prior to deposition of the Pedro Castle Formation, presumably in association with the development of the Cayman Unconformity (Jones and Hunter, 1994b).

6.2 Differential Cementation

Cementation of the Cayman Formation on Grand Cayman is not a homogeneous feature. Matrix porosity which is an inverse measure of cementation, is variable throughout the Cayman Formation. The Cayman Formation recovered from wells SOT #1 and SOT #2 is soft and poorly indurated relative to that of SOT #3. Lateral differences in matrix porosity between strata that form the peripheral ridge and strata recovered elsewhere in the Tarpon Springs area is therefore a diagenetic feature. This indicates that diagenetic conditions were variable even in this small area.

Lateral differences in matrix porosity of the Cayman Formation are also evident on a regional scale. Matrix porosity along the windward peripheral margin of the Cayman Formation is much lower relative to that of interior regions. Quantitative measurements of matrix porosity from well RWP #2 drilled on the northeast corner of the island (Figure 6.3) are typically less than 10% with an average of ~5% (Jones, pers. comm.). In contrast, matrix porosity from the interior of the island (well LV #2) averages 30% with values commonly in excess of 45% (Jones, pers. comm.). The Cayman Formation recovered from RWP #2 is directly comparable to the Cayman Formation recovered from SOT #3 in the Tarpon Springs area. Similarities with regards to matrix porosity indicates that these areas have been affected by similar diagenetic processes.

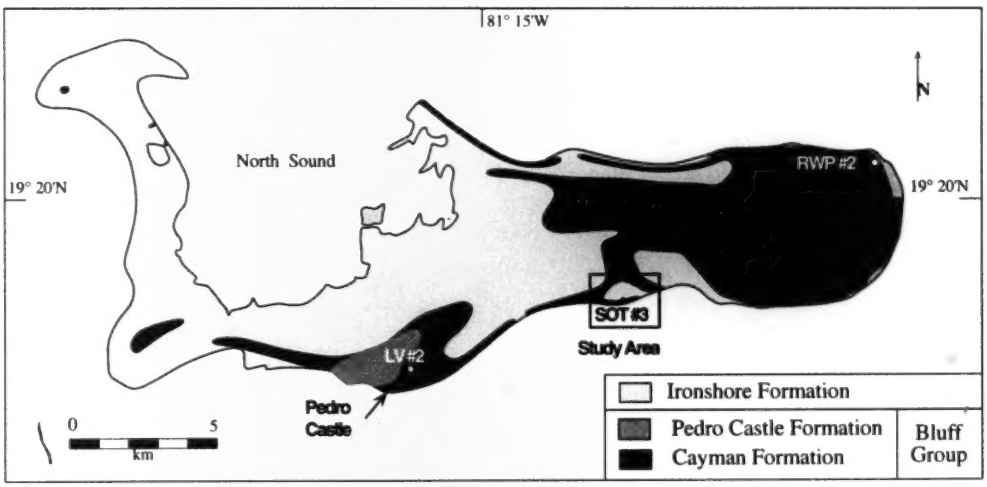

Figure 6.3: Surficial geology of Grand Cayman showing surface location of wells with low matrix porosity in the Cayman Formation (modified from Jones *et al.*, 1984).

The northeastern and southern peripheral margins of the Cayman Formation have been preferentially cemented relative to interior areas. The peripheral margins of Grand Cayman experience a constant flushing of water through pores due to the activity of waves and tidal pumping. The constant flushing of pores with water probably promotes cementation. This would eventually produce a well cemented zone, the lateral extent of which, would be controlled by wave intensity, wave strength and permeability of the bedrock. The effect of wave flushing diminishes inland as the energy dissipates. Assuming initial permeability values are similar for all coastal areas, the well cemented zone should have a greater lateral extent on windward margins relative to leeward margins due to the increase in wave intensity and strength. Wave flushing and tidal pumping during the Late Miocene regression resulted in preferential cementation of peripheral margins of Grand Cayman (Figure 6.4).

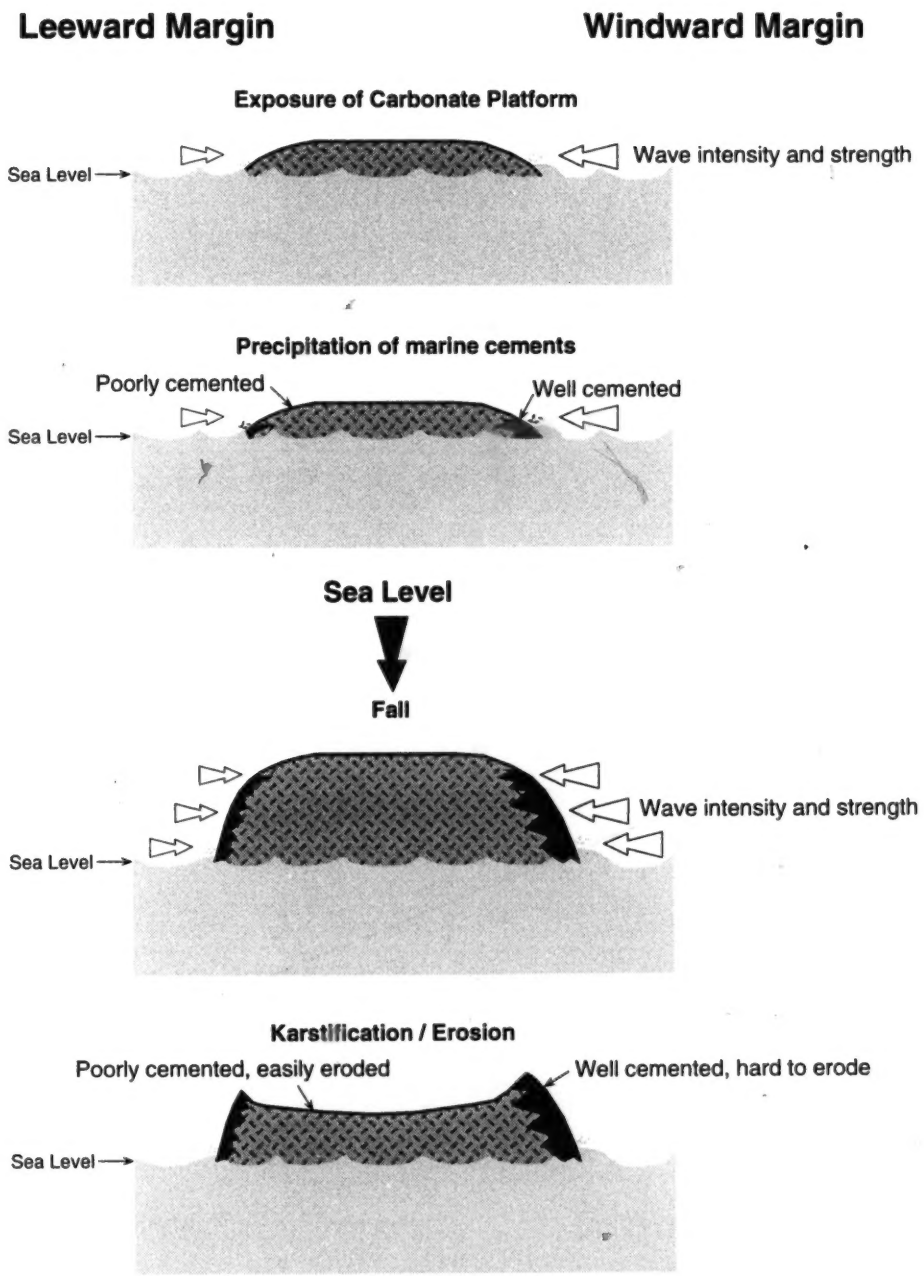

Figure 6.4: Development of laterally restricted, marine cemented peripheral margins from wave flushing and subsequent erosional of a carbonate bank.

6.3 Differences in Matrix Cementation

Matrix cementation is a variable feature in the Cayman Formation of Grand Cayman. Lateral differences in matrix cementation exist between the strata of peripheral margins and the interior areas; however, the type of matrix cement is unknown. Identification of the matrix cement itself is problematic. Pervasive dolomitization of the Cayman Formation resulted in homogenization of the matrix that has masked and/or destroyed any evidence of the precursor matrix cement. Matrix cement in the Cayman Formation may be a primary dolomite cement akin to the replacement matrix dolomite or the cement could be so fine that we have not yet leaned how to recognize it. Alternatively, differences in cementation may be related to the presence of marine micrite cement in the peripheral margins of the Cayman Formation.

Direct evidence of marine cementation in the Cayman Formation is rare. Choquette and James (1984) suggested that marine cements may consist of micrite (i.e. crystals less than 4 μm long) that cannot be resolved microscopically. Micrite, herein used in the nongenetic sense for particles less than 4 μm long (*cf.* Jones, 1989), is a common component in the matrix of the rocks that form the Cayman Formation. This micrite, however, has always been assumed to be depositional in origin. Nevertheless it is possible that some of this micrite could be a cement that was precipitated by wave flushing and tidal pumping during the Late Miocene regression. The problem, however, is now one of identifying the depositional as opposed to the diagenetic micrite. This problem exists because pervasive dolomitization of the Cayman Formation has homogenized the matrix, thereby masking any differences that may have once existed between the two types of micrite.

6.4 Differential Erosion

Erosional topography developed on the Cayman Unconformity of Grand Cayman is analogous to the erosional topography developed on limestone terraces elsewhere in the world (Jones and Hunter, 1994b). The development of topographic features by differential erosion has been proven experimentally (e.g., Hoffmeister and Ladd, 1945; Purdy, 1974). The most compelling experimental evidence was provided by Purdy (1974) who exposed blocks of limestone to varying amounts of "acid rain" (2% HCl solution). Based on the dissolutional patterns developed on the blocks, Purdy (1974) concluded that the delivery rate (rate of supply) of the "acid rain" controlled topography. Acid rain collects on the surface creating an acidic surface film. This surface film is thinnest at the margin or edges as excess fluid flows down the sides of the block. The thin acidic film located at the margins does not dissolve carbonate as fast as the thicker film in the interior (Purdy, 1974). The preferential dissolution of carbonate from interior areas created a raised peripheral ridge. Three distinct dissolutional patterns were created by varying the rate of water (acid rain) supply (Figure 6.5).

Development of the peripheral ridge on the Cayman Unconformity has been compared to Purdy's karst model (Jones and Hunter, 1994b). Dissolution of the Cayman Formation by rainwater during the Miocene resulted in the development of the peripheral ridge and central depression. Miocene rainwater preferentially collected in the central region of the island. Dissolution was therefore more pronounced in the central region of the island relative to the peripheral regions (Jones and Hunter, 1994b). Topographic differences between the western and eastern parts of the island were related to differential paleorainfall. The possibility of such a condition is supported by present day rainfall patterns which indicate that the western half of Grand Cayman receives more rain per annum than the eastern half.

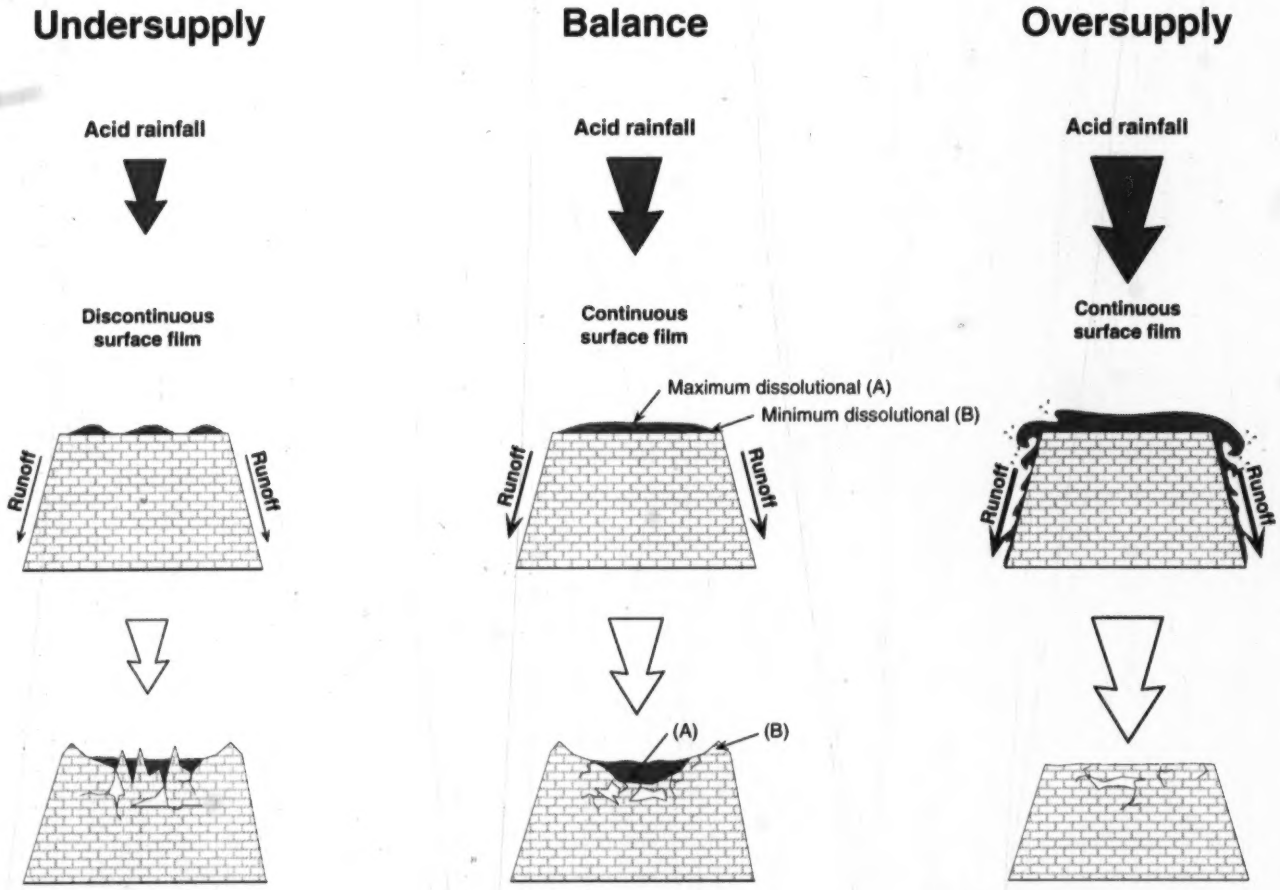

Figure 6.5: Dissolution patterns developed on limestone blocks with varying rates of water (acid rain) supply (modified from Purdy, 1974).

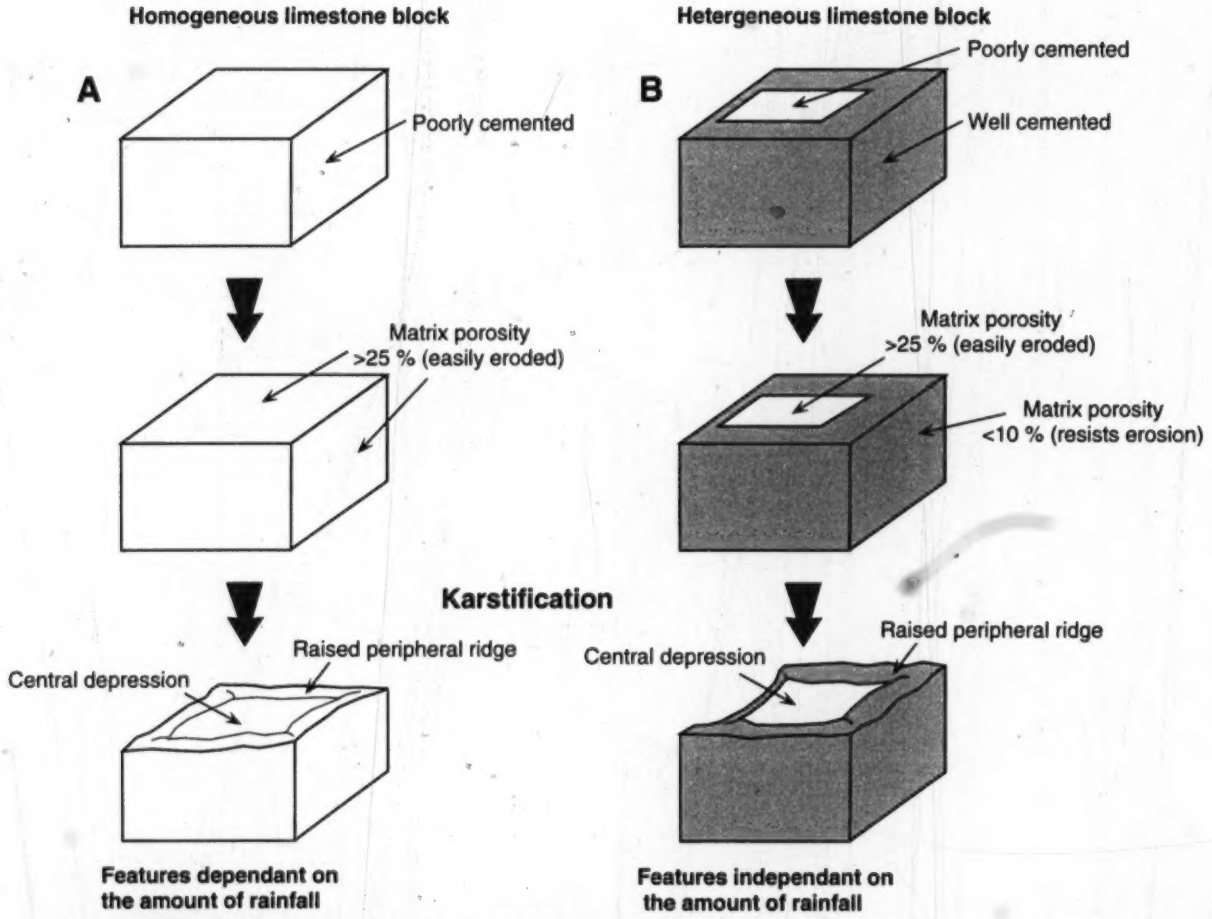

Figure 6.6: Development of a erosional topography on (A) a homogeneous limestone block and (B) a heterogeneous block with preferentially cemented peripheral margins.

The erosional topography created experimentally by Purdy was developed on relatively homogeneous limestone blocks. By comparison, a peripheral ridge and central depression could be developed on a limestone block exhibiting heterogeneities with regards to matrix porosity (Figure 6.6). Areas with low matrix porosity would be more resistant to erosion relative to those areas with higher matrix porosity. Preferential cementation of the peripheral margins prior to or during the period of dissolution would render these margins more resistant to erosion than the uncemented areas. Dissolution would therefore preferentially remove material from the interior of the block, resulting in a central depression and peripheral ridge (Figure 6.6). The resulting erosional topography is independant of the rate of water (acid rain) supply.

Topography developed on the Cayman Unconformity is the result of diagenetic and erosional processes. Preferential erosion of porous, poorly cemented interior zones relative to the non porous, well cemented peripheral margins of the Cayman Formation resulted in the development of the central depression and raised peripheral ridge. Topographic differences between the western and eastern regions of the island is related to the degree of matrix cementation and possibly varying paleorainfall. Marine cementation of the peripheral margins was best developed along the windward margins of the island. Erosion of the western leeward peripheral margin was therefore more pronounced relative to the windward margins of Grand Cayman. This differential erosion would have been further accentuated by the increased precipitation on the western half of the island during the Late Miocene.

6.5 Post Messinian Erosion

The Cayman Formation and Ironshore Formation form most of the surficial geology of Grand Cayman. Exposures of the Pedro Castle Formation are limited to an area around Pedro Castle Formation. The Pedro Castle Formation is, however, relatively common in the subsurface of the western part of the island (Jones, 1994). By comparison

the Pedro Castle Formation is rare on the eastern part of Grand Cayman being restricted to topographic lows (sinkholes).

The Pedro Castle Formation was deposited during a sea level highstand period in the Lower to Middle Pliocene (Jones *et al.*, 1994; Wignall, 1995). Sea level during this highstand estimated to have been 35 m (+/- 18 m) above present day sea level, persisted for approximately 0.5 million years (Dowsett and Cronin, 1990). Exposures of the Pedro Castle Formation on Grand Cayman have a maximum elevation of 15 m above present day sea level. The elevation of these exposures indicate that sea level during deposition of the Pedro Castle Formation was greater than 15 m above present day sea level (Wignall, 1995). Sea level must have been greater than 15 m asl because these exposures of the Pedro Castle Formation are presently being subjected to erosional processes. The existence of a Pliocene sea level in excess of 15 m asl would have inundated most of Grand Cayman with sea water. The distribution of the Pedro Castle Formation in the subsurface of the western peninsula (i.e. SH #3) and in sinkholes developed on the eastern part of the island (i.e. QHW #1) indicates that deposition was a regional phenomena. Nevertheless the Pedro Castle Formation is absent from Tarpon Springs Estates presumably because it has since been removed by erosion.

Sea level fluctations caused by the onset of glacial cooling in the late Middle Pliocene subjected the Pedro Castle Formation on Grand Cayman to intermittent subaerial and submarine conditions (Cronin *et al.*, 1994; Wignall, 1995). Erosion of the Pedro Castle Formation in the Tarpon Springs area took place during this period of fluctuating sea levels prior to deposition of the Ironshore Formation (Member D) 130 000 to 120 000 years ago.

Erosional processes responsible for removing the Pedro Castle Formation from the study area appear to have modified the Cayman Unconformity. The topography and textures of the Cayman Unconformity are preferentially preserved where it is directly overlain by the Pedro Castle Formation. In these areas the Cayman Unconformity has

been modified by marine processes (Wignall, 1995). This unconformity surface is, for example commonly penetrated by worm, sponge and bivalve borings (e.g., Pedro Castle Quarry - Jones and Hunter, 1994b). These borings were subsequently filled with sediment of the Pedro Casle Formation. Borings and/or cavities filled with sediment belonging to the Pedro Castle Formation are absent from the Unconformity preserved in the study area. These features appear to have been removed by the erosional processes responsible for removal of the Pedro Castle Formation from the study area.

The exact amount of rock removed from the Cayman Formation in the study area during the Late Pliocene is unknown. This is because the duration of the intermittent periods of subaerial exposure following the erosion of the Pedro Castle Formation are unknown. The age difference between the Pedro Castle Formation and the Ironshore Formation is approximately 1.5 Ma. Exposure and erosion of the Cayman Unconformity took place sometime during this time period but only after the Pedro Castle Formation was removed from the study area. In comparison to the Cayman Unconformity preserved in the subsurface elsewhere on Grand Cayman, the only feature absent from the unconformity surface in the study area appears to be sediment filled borings. The absence of these bioerosion features suggests a minimum amount of erosion of several centimeters. The removal of any amount greater than several centimeters is conjecture.

Conclusions

Surface exposures and core recovered from three wells drilled in the Tarpon Springs area record the sedimentology, depositional architecture, and diagenesis of the Cayman Formation. A detailed analysis of the material has led to the following conclusions:

1) The Cayman Formation encompasses nine facies that belong to three depositional units. Each unit is bound by disconformable or discontinuity surfaces and contains genetically related facies that were deposited under similar environmental conditions.
2) Deposition of the Cayman Formation took place under normal marine conditions on an unrimmed open bank setting, under moderately high energy conditions in water 10 -35 m deep.
3) Units II and III of the Cayman Formation are similar to the middle and upper parts of the Cayman Formation on Cayman Brac, respectively.
4) The complex diagenesis of the Cayman Formation encompassed numerous processes that were repeated several times in the diagenetic history of the formation.
5) Pervasive matrix dolomitization and formation of dolomite cements were probably time separated events. Type A dolomite cements were probably precipitated during the early phases of the Messinian lowstand whereas matrix dolomitization appears to have taken place sometime later between 2 - 5 Ma.
6) Dolomitization fabrics developed in the Cayman Formation may have formed from two different parent fluids in two different environments. The nature and localized distribution of Type A meteoric dolomite cements indicates a mixed meteoric marine water origin. In comparison, the pervasive nature of Type I matrix dolomite suggests a regionally extensive dolomitizing fluid such as normal marine water.

7) Matrix porosity in the Cayman Formation is heterogeneous.

8) Matrix porosity in the Cayman Formation along the peripheral margins is much lower relative to that of interior regions.

9) Wave flushing and tidal pumping during the Late Miocene regression resulted in the preferential cementation of the peripheral margins of the island.

10) The topography developed on the Cayman Unconformity was the result of preferential cementation and erosion. Preferential erosion of the poorly cemented interior regions relative to the well cemented peripheral margins resulted in the development of a centralized depression and raised peripheral ridge.

11) Erosion during the Late Pliocene removed the Pedro Castle Formation and modified the Cayman Unconformity.

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APPENDIX

Core Descriptions

Legend

Lithology

Dolomite

Limestone

Accessories

Caymanite

Cavity

Terra rossa

No recovery

Rhizolith

Calcrete

Fossils

Rhodolite (algae nucleus)

Amphistegina

Gastropod

Rhodolite (coral nucleus)

Foraminifera

Stylophora

Halimeda

Fragmented massive coral

Stylophora fragment

Bivalve

Fragmented and coralline algal encrusted massive coral

Coralline algal encrusted *Stylophora* fragment

Bivalve fragment

Free living coral

Porites

Echinoid spine

Fragmented free living coral

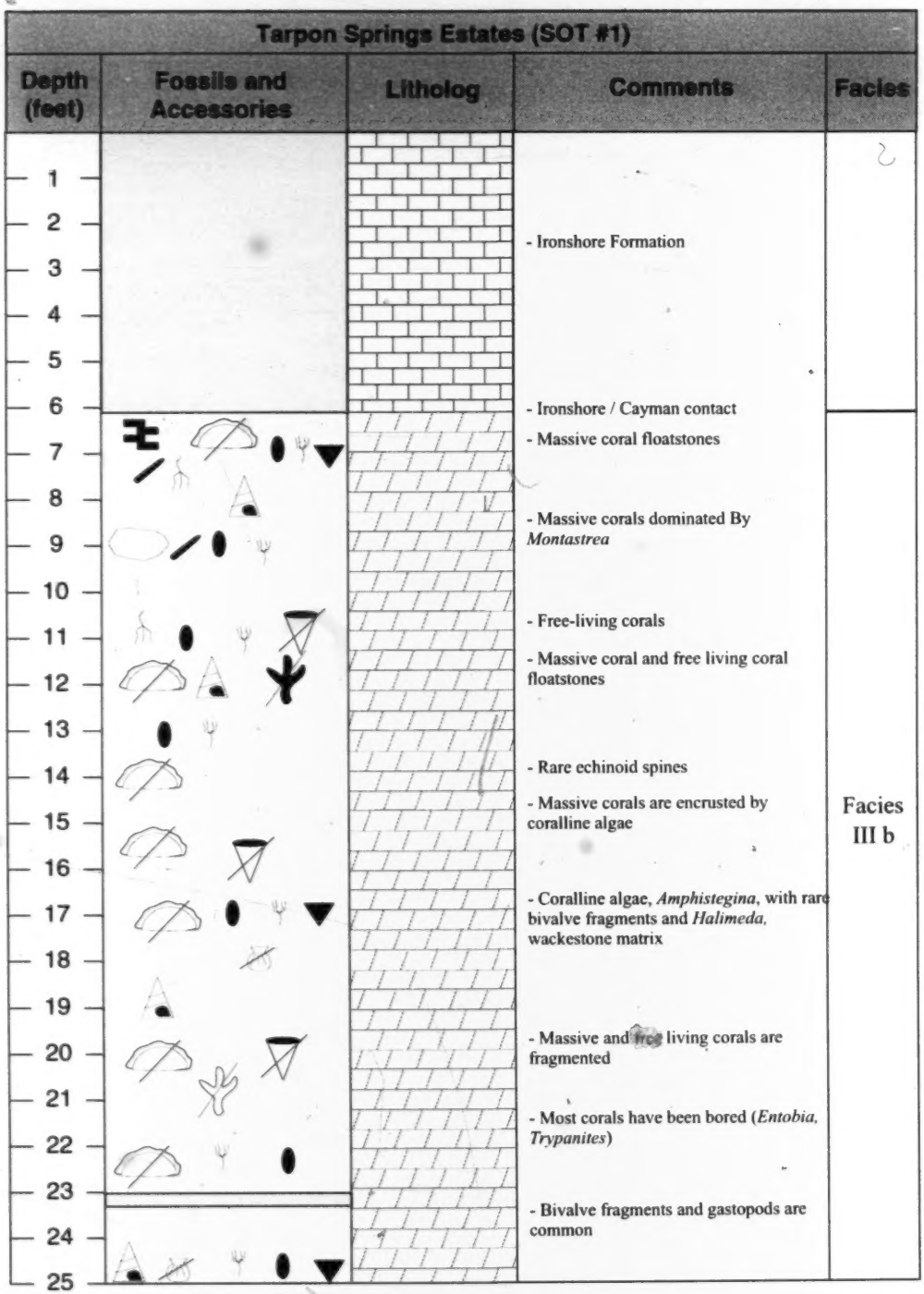
Porites fragment

Coralline algae

Laminar coral

Coralline algal encrusted *Porites* fragment

Fragmented laminar coral


Tarpon Springs Estates (SOT #1)
Depth (feet)
Fossils and Accessories
Litholog
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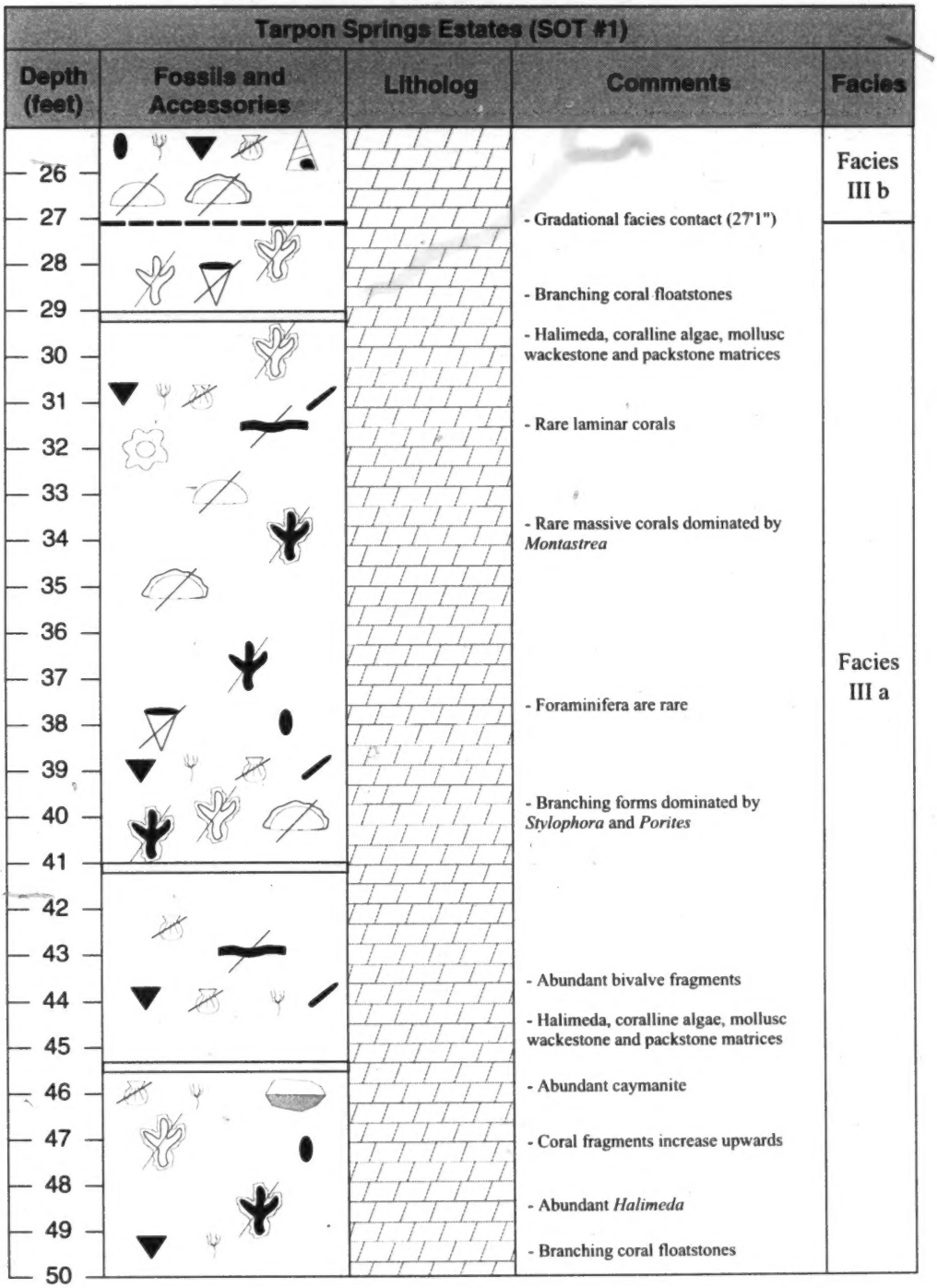
- Ironshore Formation
- Ironshore / Cayman contact
- Massive coral floatstones
- Massive corals dominated By Montastrea
- Free-living corals
- Massive coral and free living coral floatstones
- Rare echinoid spines
- Massive corals are encrusted by coralline algae
- Coralline algae, Amphistegina, with rare bivalve fragments and Halimeda, wackestone matrix
- Massive and free living corals are fragmented
- Most corals have been bored (Entobia, Trypanites)
- Bivalve fragments and gastopods are common
Facies III b


Tarpon Springs Estates (SOT #1)
Depth (feet)
Fossils and Accessories
Litholog
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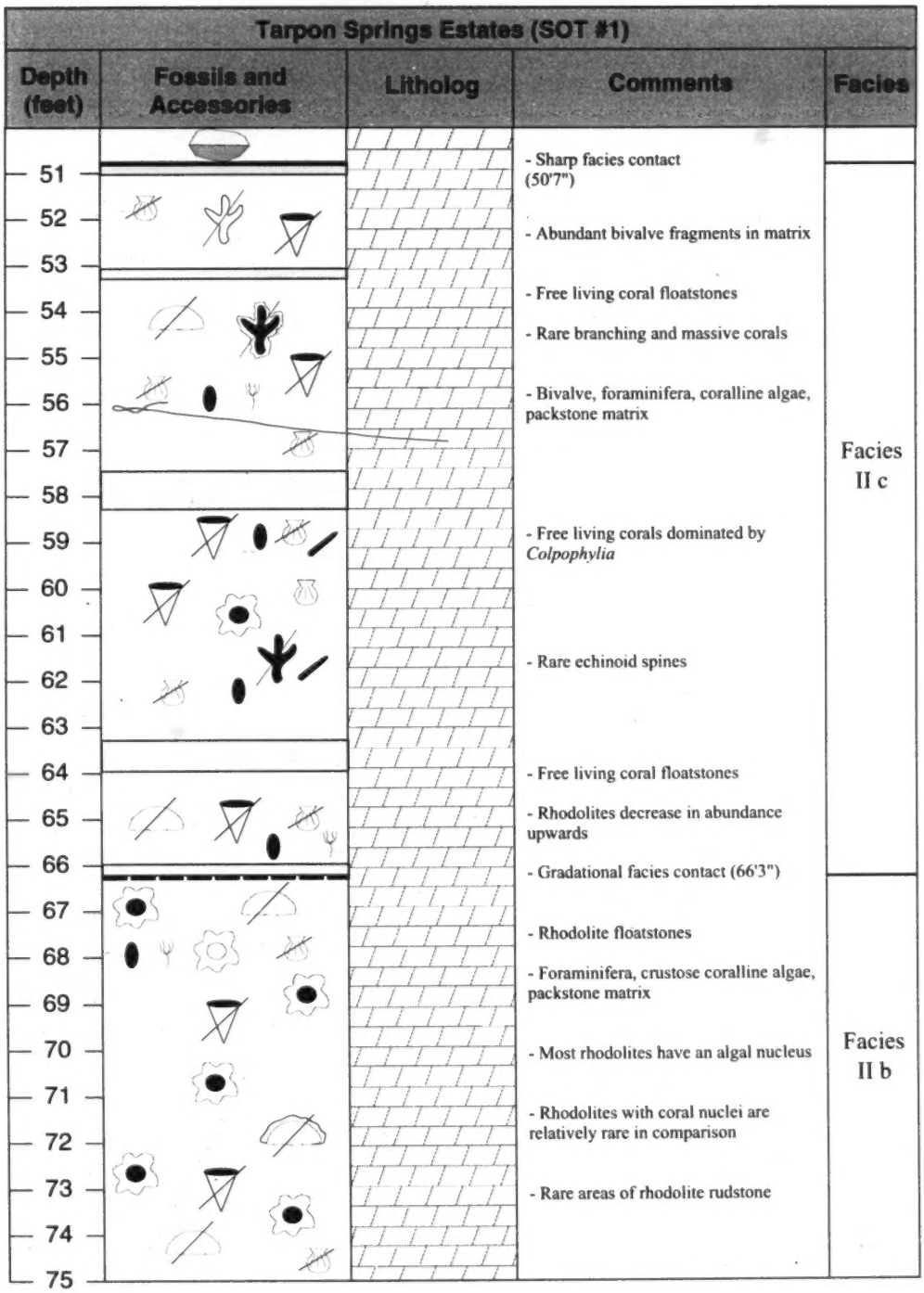
- Gradational facies contact (27'1")
- Branching coral floatstones
- Halimeda, coralline algae, mollusc wackestone and packstone matrices
- Rare laminar corals
- Rare massive corals dominated by *Montastrea*
- Foraminifera are rare
- Branching forms dominated by *Stylophora* and *Porites*
- Abundant bivalve fragments
- Halimeda, coralline algae, mollusc wackestone and packstone matrices
- Abundant caymanite
- Coral fragments increase upwards
- Abundant *Halimeda*
- Branching coral floatstones
Facies III b
Facies III a


Tarpon Springs Estates (SOT #1)
Depth (feet)
Fossils and Accessories
Litholog
Comments
Facies
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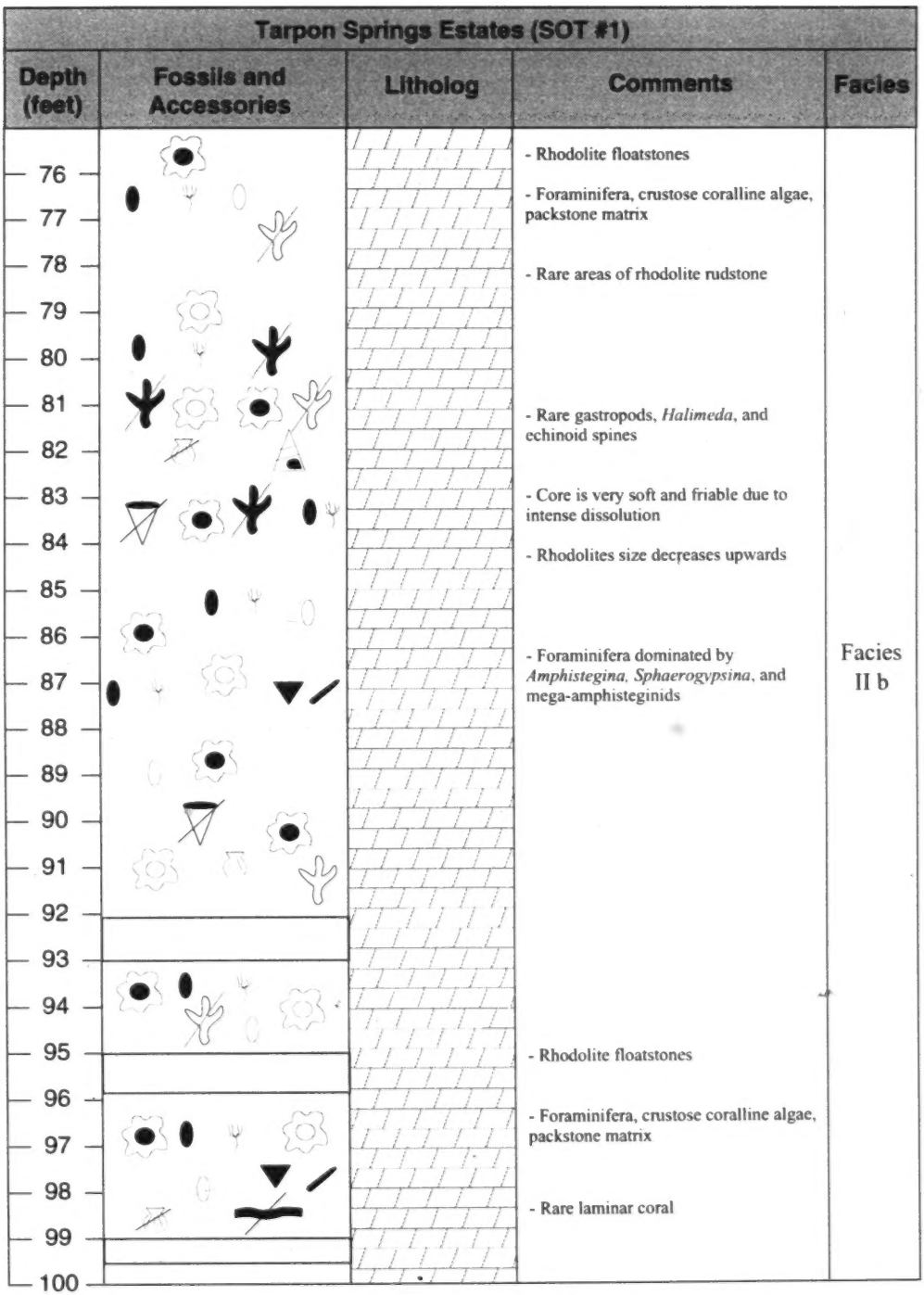
- Sharp facies contact (50'7")
- Abundant bivalve fragments in matrix
- Free living coral floatstones
- Rare branching and massive corals
- Bivalve, foraminifera, coralline algae, packstone matrix
- Free living corals dominated by *Colpophylia*
- Rare echinoid spines
- Free living coral floatstones
- Rhodolites decrease in abundance upwards
- Gradational facies contact (66'3")
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, packstone matrix
- Most rhodolites have an algal nucleus
- Rhodolites with coral nuclei are relatively rare in comparison
- Rare areas of rhodolite rudstone
Facies II c
Facies II b


Tarpon Springs Estates (SOT #1)
Depth (feet)
Fossils and Accessories
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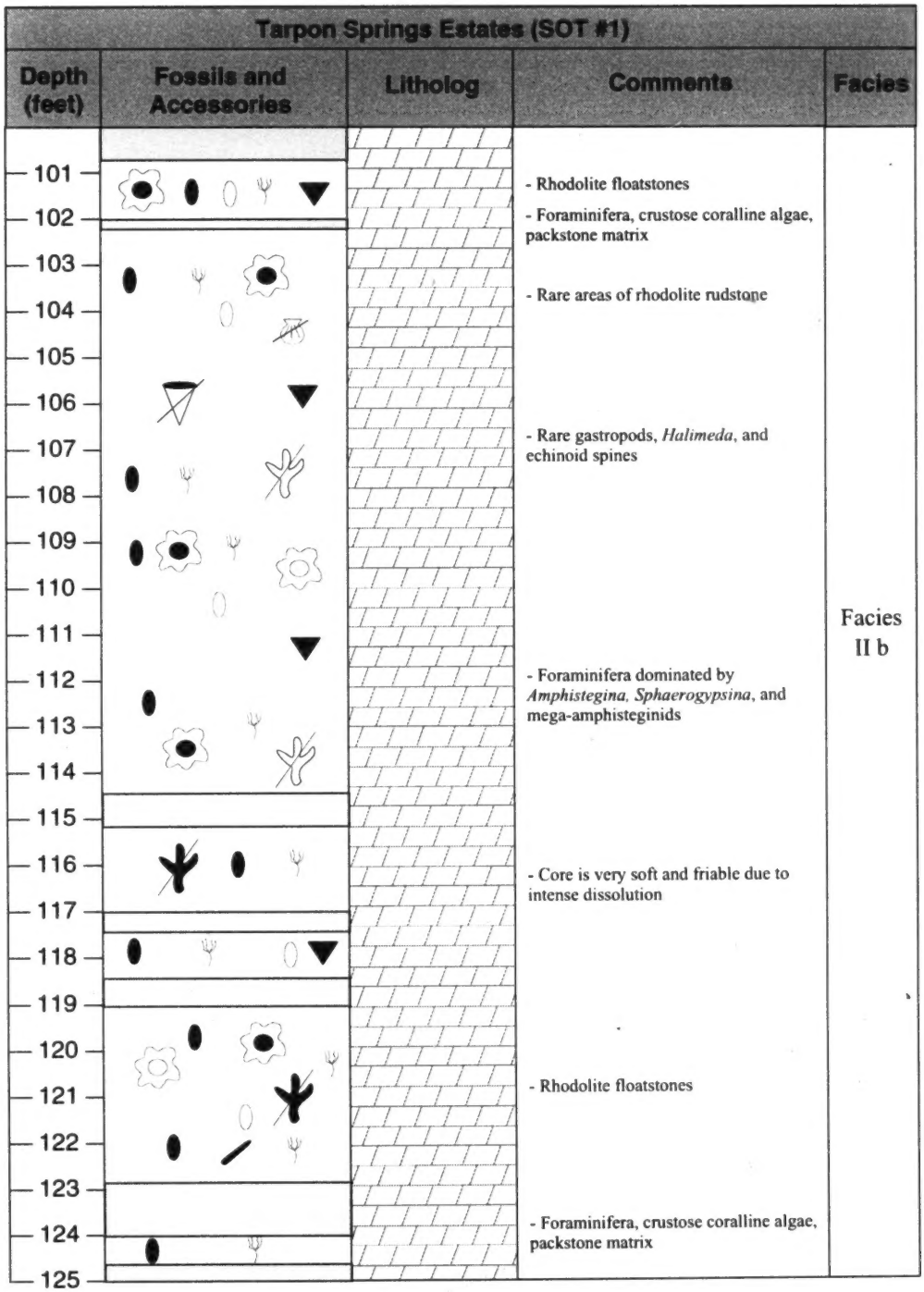
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, packstone matrix
- Rare areas of rhodolite rudstone
- Rare gastropods, Halimeda, and echinoid spines
- Core is very soft and friable due to intense dissolution
- Rhodolites size decreases upwards
- Foraminifera dominated by Amphistegina, Sphaerogypsina, and mega-amphisteginids
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, packstone matrix
- Rare laminar coral
Facies II b


Tarpon Springs Estates (SOT #1)
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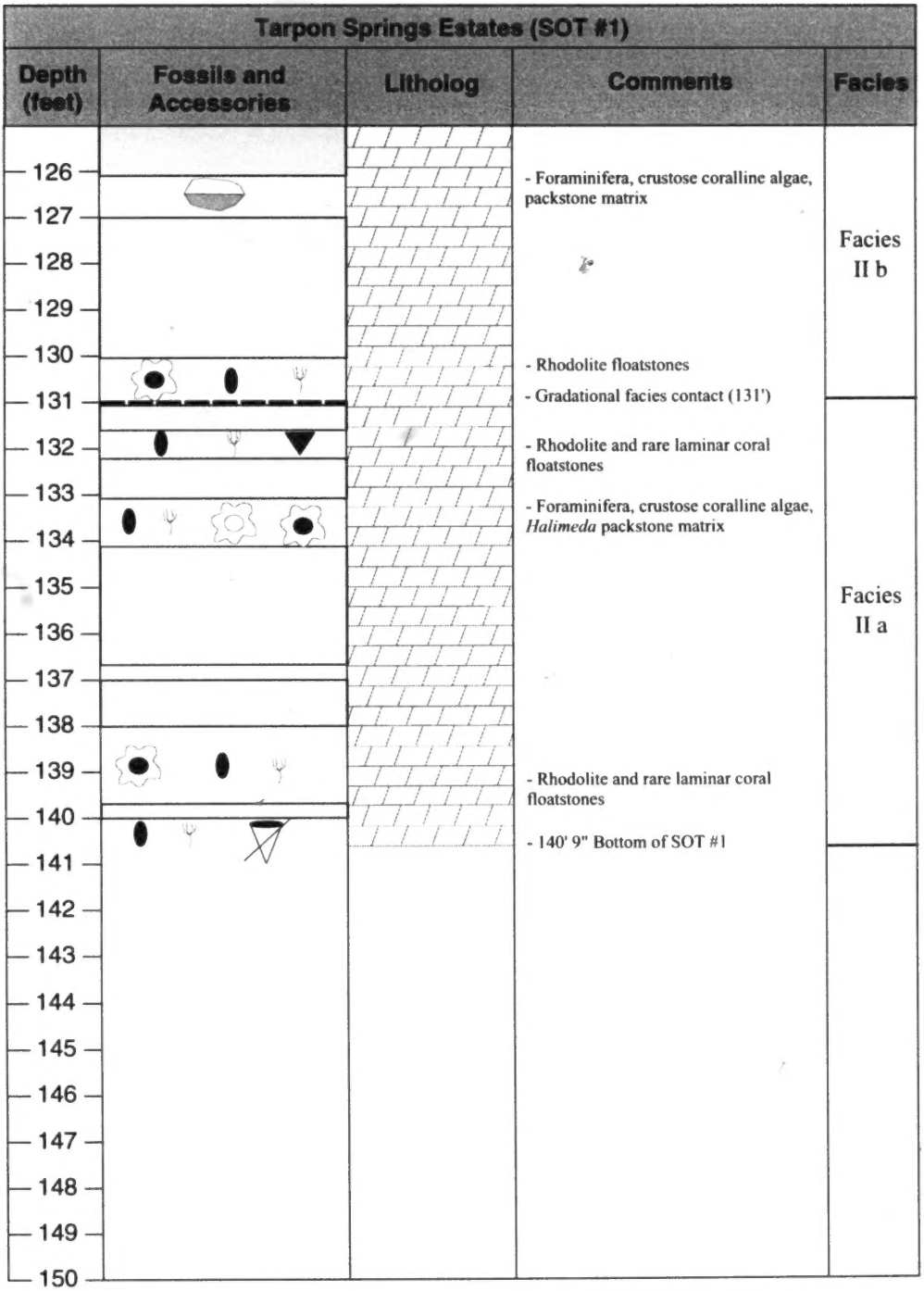
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, packstone matrix
- Rare areas of rhodolite rudstone
- Rare gastropods, Halimeda, and echinoid spines
- Foraminifera dominated by Amphistegina, Sphaerogypsina, and mega-amphisteginids
- Core is very soft and friable due to intense dissolution
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, packstone matrix
Facies II b


Tarpon Springs Estates (SOT #1)
Depth (feet)
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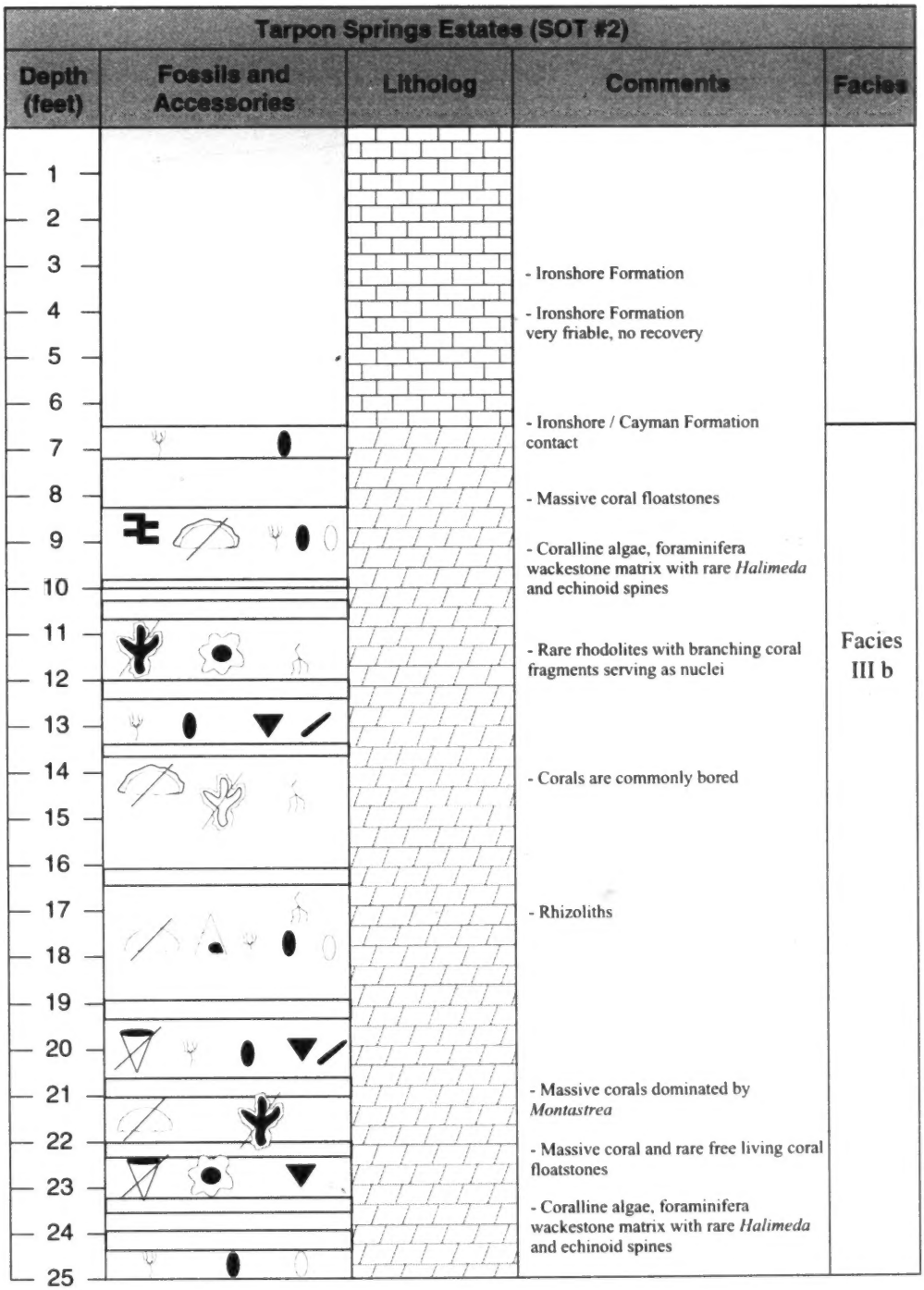
- Foraminifera, crustose coralline algae, packstone matrix
- Rhodolite floatstones
- Gradational facies contact (131')
- Rhodolite and rare laminar coral floatstones
- Foraminifera, crustose coralline algae, Halimeda packstone matrix
- Rhodolite and rare laminar coral floatstones
- 140' 9" Bottom of SOT #1
Facies II b
Facies II a


Tarpon Springs Estates (SOT #2)
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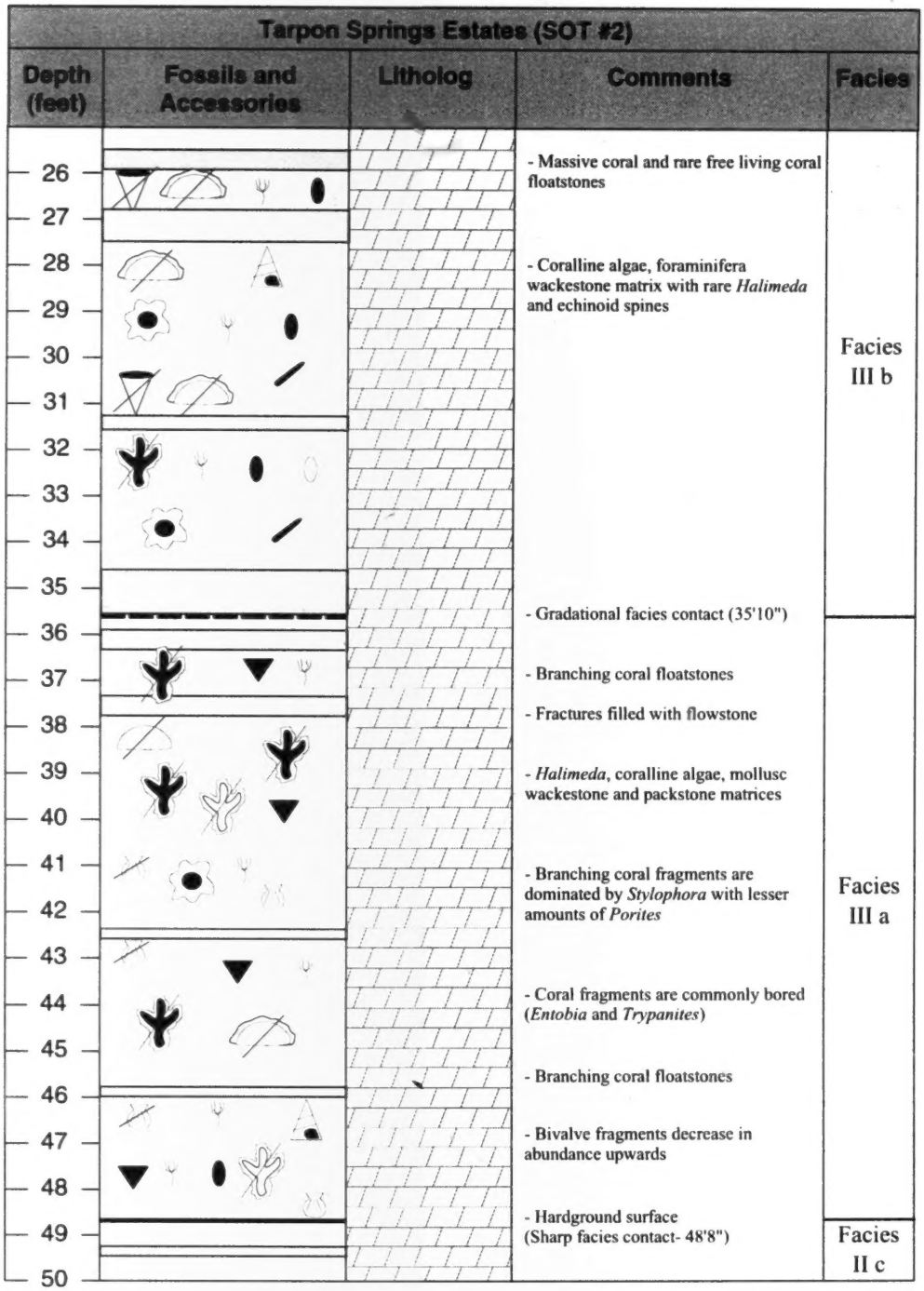
- Ironshore Formation
- Ironshore Formation very friable, no recovery
- Ironshore / Cayman Formation contact
- Massive coral floatstones
- Coralline algae, foraminifera wackestone matrix with rare *Halimeda* and echinoid spines
- Rare rhodolites with branching coral fragments serving as nuclei
- Corals are commonly bored
- Rhizoliths
- Massive corals dominated by *Montastrea*
- Massive coral and rare free living coral floatstones
- Coralline algae, foraminifera wackestone matrix with rare *Halimeda* and echinoid spines
Facies III b


Tarpon Springs Estates (SOT #2)
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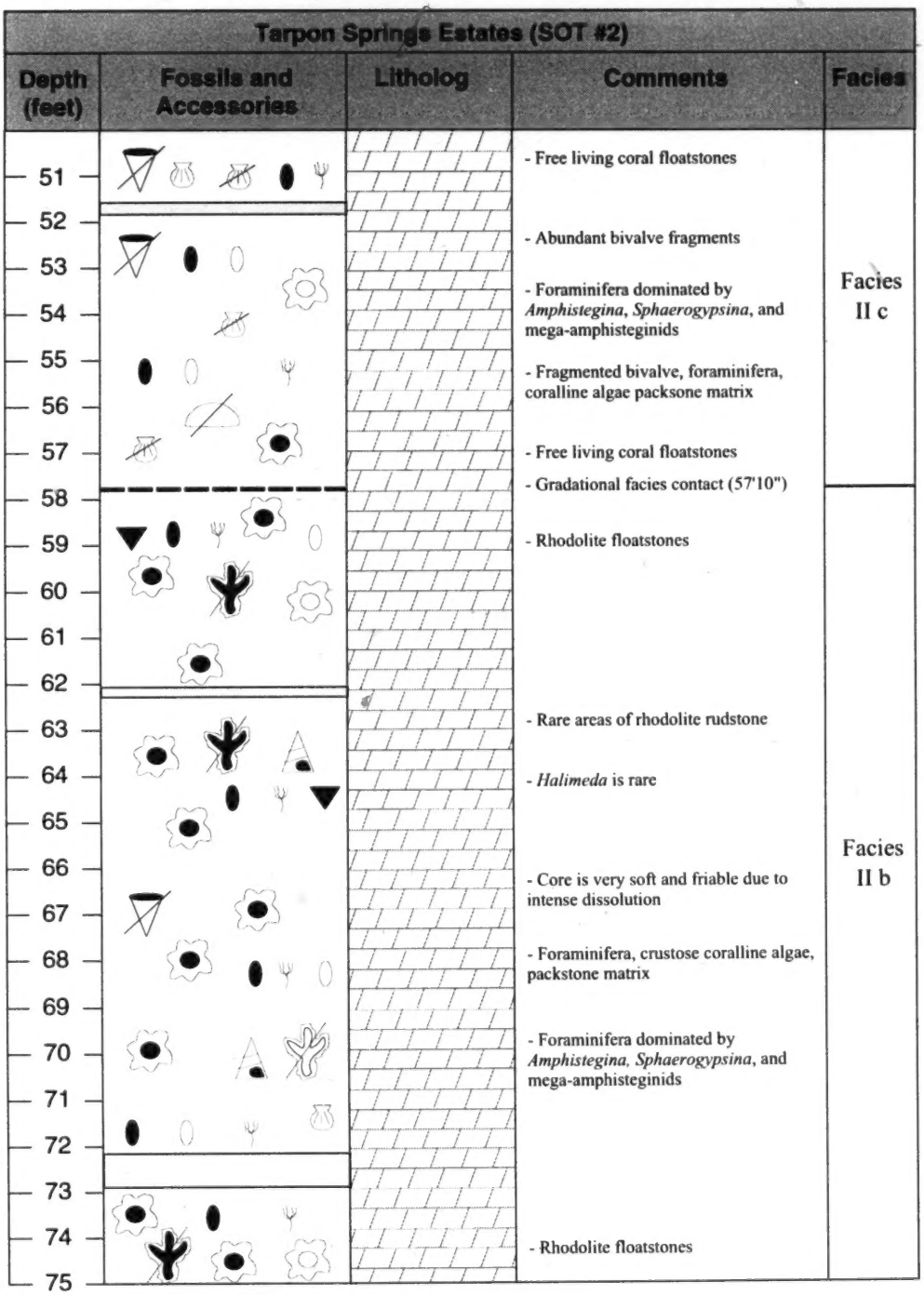
- Massive coral and rare free living coral floatstones
- Coralline algae, foraminifera wackestone matrix with rare Halimeda and echinoid spines
Facies III b
- Gradational facies contact (35'10")
- Branching coral floatstones
- Fractures filled with flowstone
- Halimeda, coralline algae, mollusc wackestone and packstone matrices
- Branching coral fragments are dominated by Stylophora with lesser amounts of Porites
Facies III a
- Coral fragments are commonly bored (Entobia and Trypanites)
- Branching coral floatstones
- Bivalve fragments decrease in abundance upwards
- Hardground surface
(Sharp facies contact- 48'8")
Facies II c


Tarpon Springs Estates (SOT #2)
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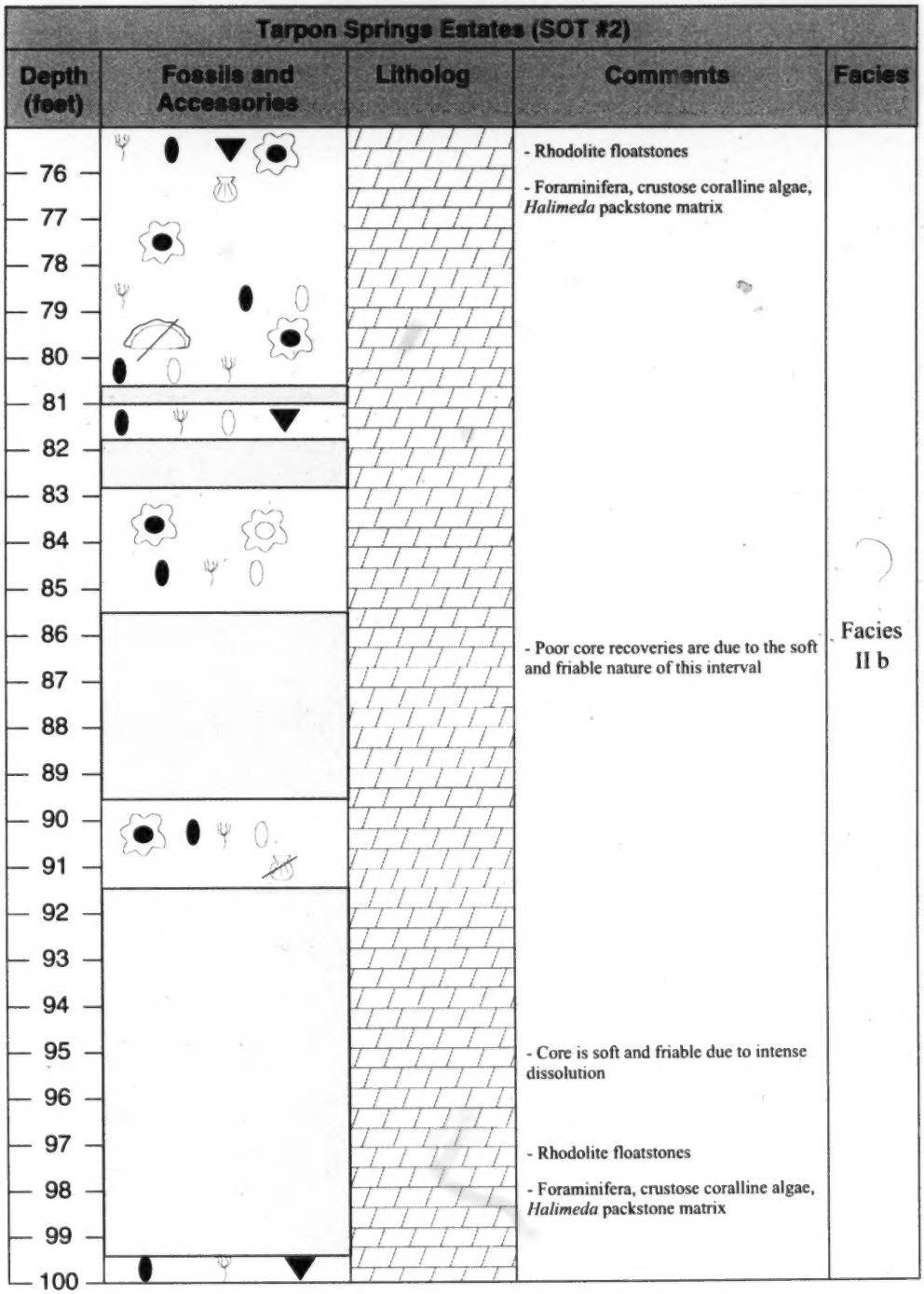
- Free living coral floatstones
- Abundant bivalve fragments
- Foraminifera dominated by *Amphistegina*, *Sphaerogypsina*, and mega-amphisteginids
- Fragmented bivalve, foraminifera, coralline algae packsone matrix
- Free living coral floatstones
- Gradational facies contact (57'10")
- Rhodolite floatstones
- Rare areas of rhodolite rudstone
- *Halimeda* is rare
- Core is very soft and friable due to intense dissolution
- Foraminifera, crustose coralline algae, packstone matrix
- Foraminifera dominated by *Amphistegina, Sphaerogypsina*, and mega-amphisteginids
- Rhodolite floatstones
Facies II c
Facies II b


Tarpon Springs Estates (SOT #2)
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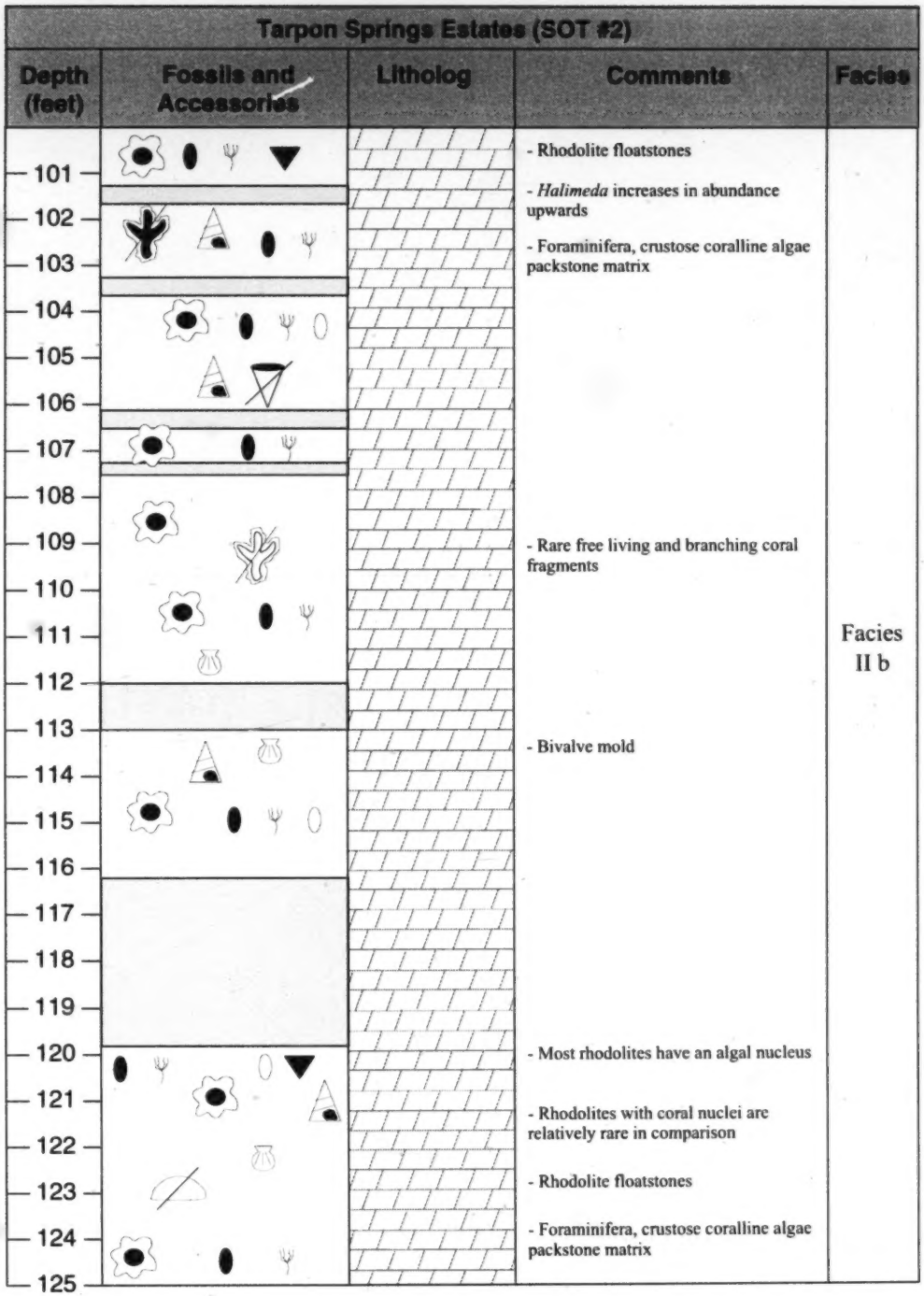
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, Halimeda packstone matrix
- Poor core recoveries are due to the soft and friable nature of this interval
- Core is soft and friable due to intense dissolution
- Rhodolite floatstones
- Foraminifera, crustose coralline algae, Halimeda packstone matrix
Facies II b


Tarpon Springs Estates (SOT #2)
Depth (feet)
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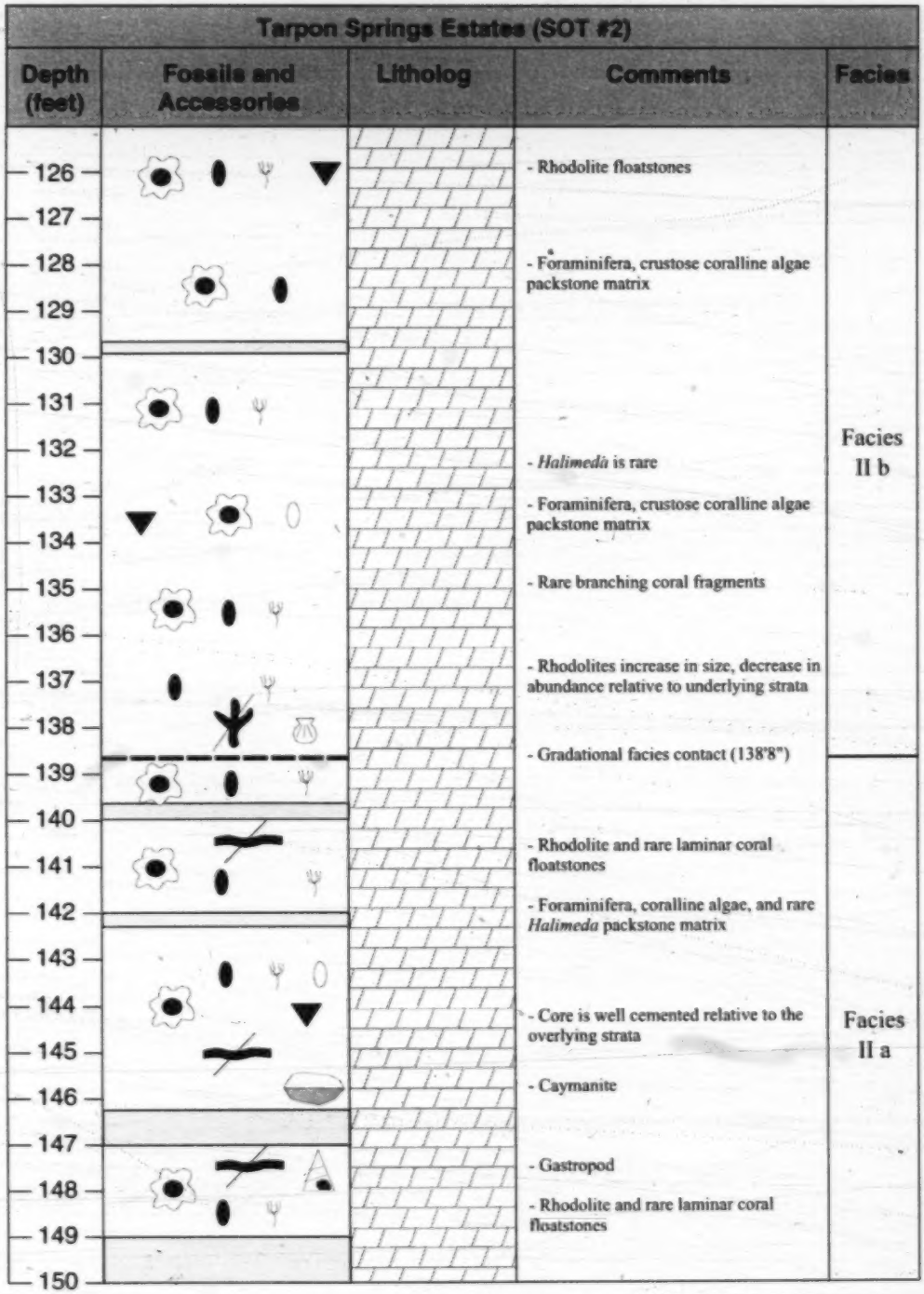
- Rhodolite floatstones
- Halimeda increases in abundance upwards
- Foraminifera, crustose coralline algae packstone matrix
- Rare free living and branching coral fragments
- Bivalve mold
- Most rhodolites have an algal nucleus
- Rhodolites with coral nuclei are relatively rare in comparison
- Rhodolite floatstones
- Foraminifera, crustose coralline algae packstone matrix
Facies II b


Tarpon Springs Estates (SOT #2)
Depth (feet)
Fossils and Accessories
Litholog
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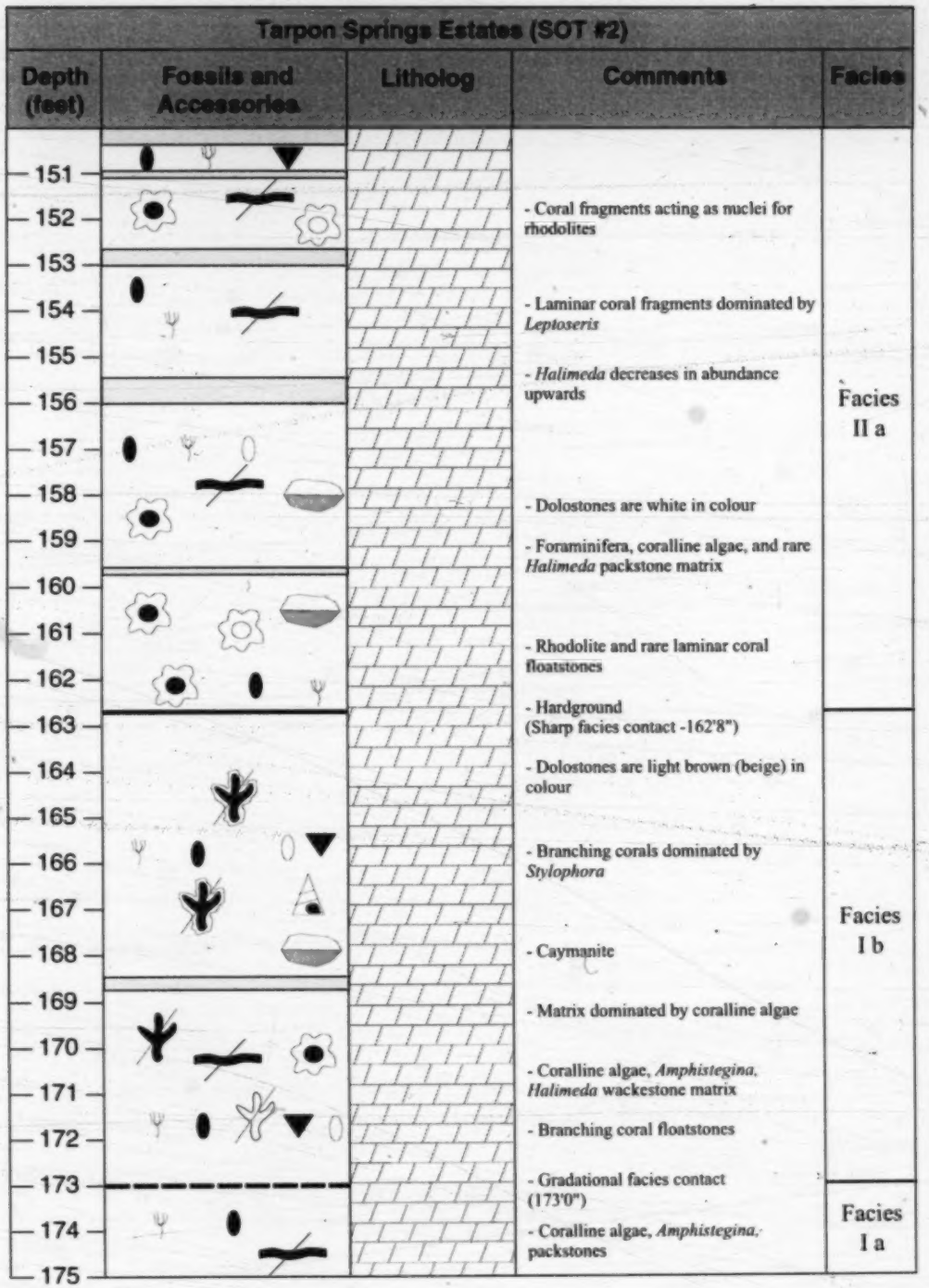
- Rhodolite floatstones
- Foraminifera, crustose coralline algae packstone matrix
- Halimeda is rare
- Foraminifera, crustose coralline algae packstone matrix
- Rare branching coral fragments
- Rhodolites increase in size, decrease in abundance relative to underlying strata
- Gradational facies contact (138'8")
- Rhodolite and rare laminar coral floatstones
- Foraminifera, coralline algae, and rare Halimeda packstone matrix
- Core is well cemented relative to the overlying strata
- Caymanite
- Gastropod
- Rhodolite and rare laminar coral floatstones
Facies II b
Facies II a


Tarpon Springs Estates (SOT #2)
Depth (feet)
Fossils and Accessories
Litholog
Comments
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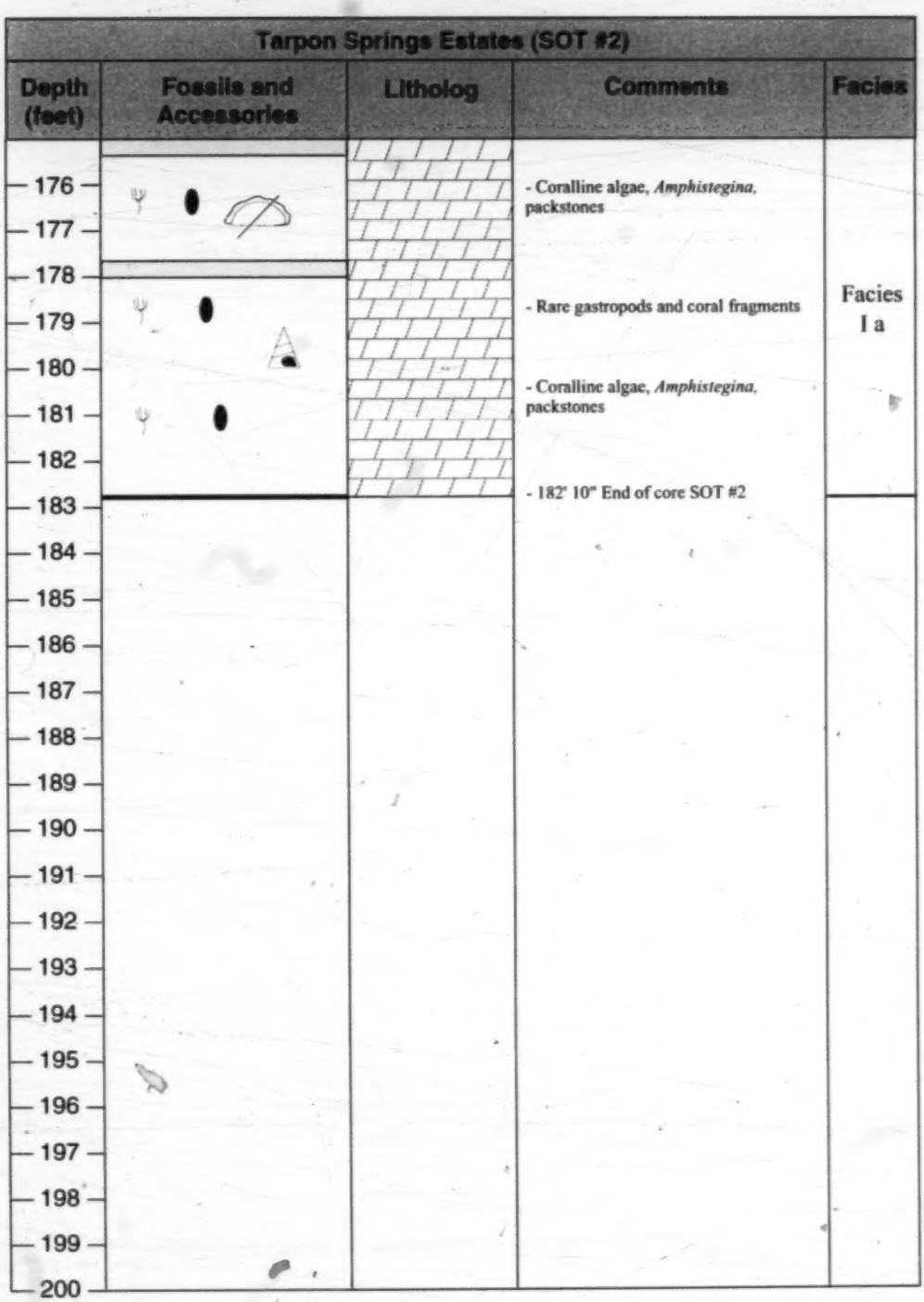
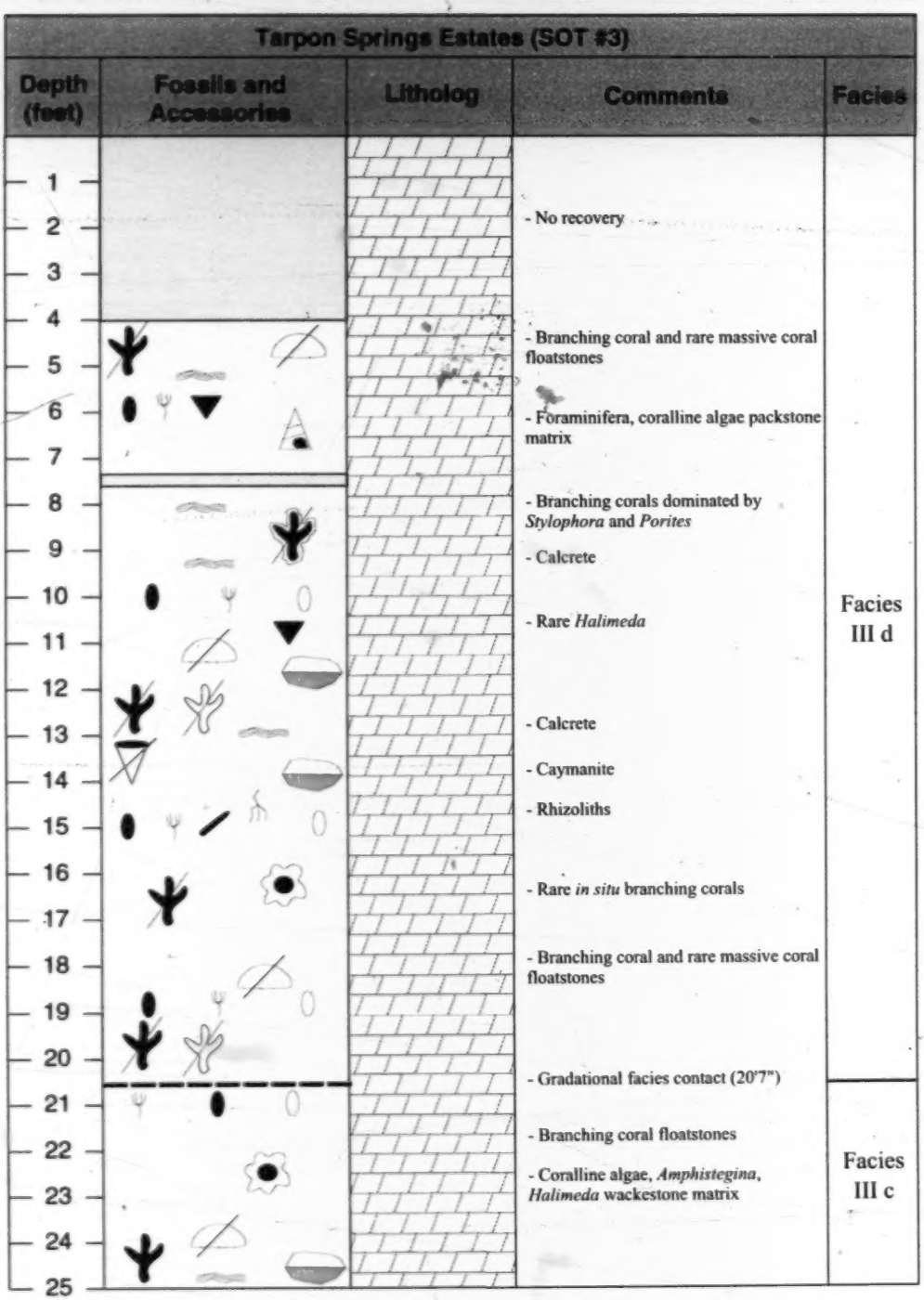
- Coral fragments acting as nuclei for rhodolites
- Laminar coral fragments dominated by Leptoseris
- Halimeda decreases in abundance upwards
- Dolostones are white in colour
- Foraminifera, coralline algae, and rare Halimeda packstone matrix
- Rhodolite and rare laminar coral floatstones
- Hardground (Sharp facies contact -162'8")
- Dolostones are light brown (beige) in colour
- Branching corals dominated by Stylophora
- Caymanite
- Matrix dominated by coralline algae
- Coralline algae, Amphistegina, Halimeda wackestone matrix
- Branching coral floatstones
- Gradational facies contact (173'0")
- Coralline algae, Amphistegina, packstones
Facies II a
Facies I b
Facies I a


Tarpon Springs Estates (SOT #2)
Depth (feet)
Fossils and Accessories
Litholog
Comments
Facies
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
- Coralline algae, Amphistegina, packstones
- Rare gastropods and coral fragments
- Coralline algae, Amphistegina, packstones
- 182' 10" End of core SOT #2
Facies I a


Tarpon Springs Estates (SOT #3)
Depth (feet)
Fossils and Accessories
Litholog
Comments
Facies
1
2
3
4
5
6
7
8
9
10
11
12
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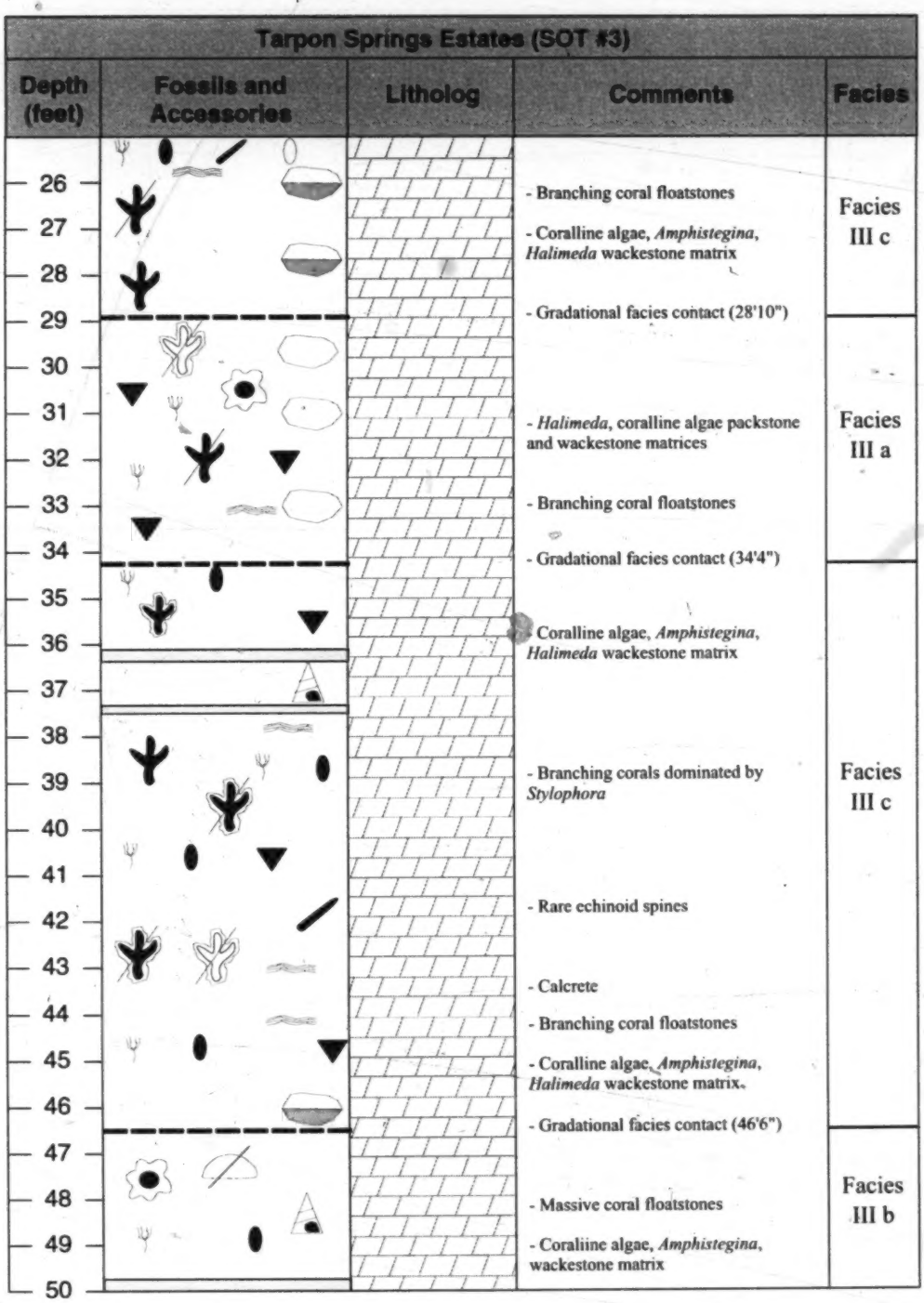
14
15
16
17
18
19
20
21
22
23
24
25
- No recovery
- Branching coral and rare massive coral floatstones
- Foraminifera, coralline algae packstone matrix
- Branching corals dominated by *Stylophora* and *Porites*
- Calcrete
- Rare *Halimeda*
- Calcrete
- Caymanite
- Rhizoliths
- Rare *in situ* branching corals
- Branching coral and rare massive coral floatstones
- Gradational facies contact (20'7")
- Branching coral floatstones
- Coralline algae, *Amphistegina*, *Halimeda* wackestone matrix
Facies III d
Facies III c


Tarpon Springs Estates (SOT #3)
Depth (feet)
Fossils and Accessories
Litholog
Comments
Facies
26
27
28
29
30
31
32
33
34
35
36
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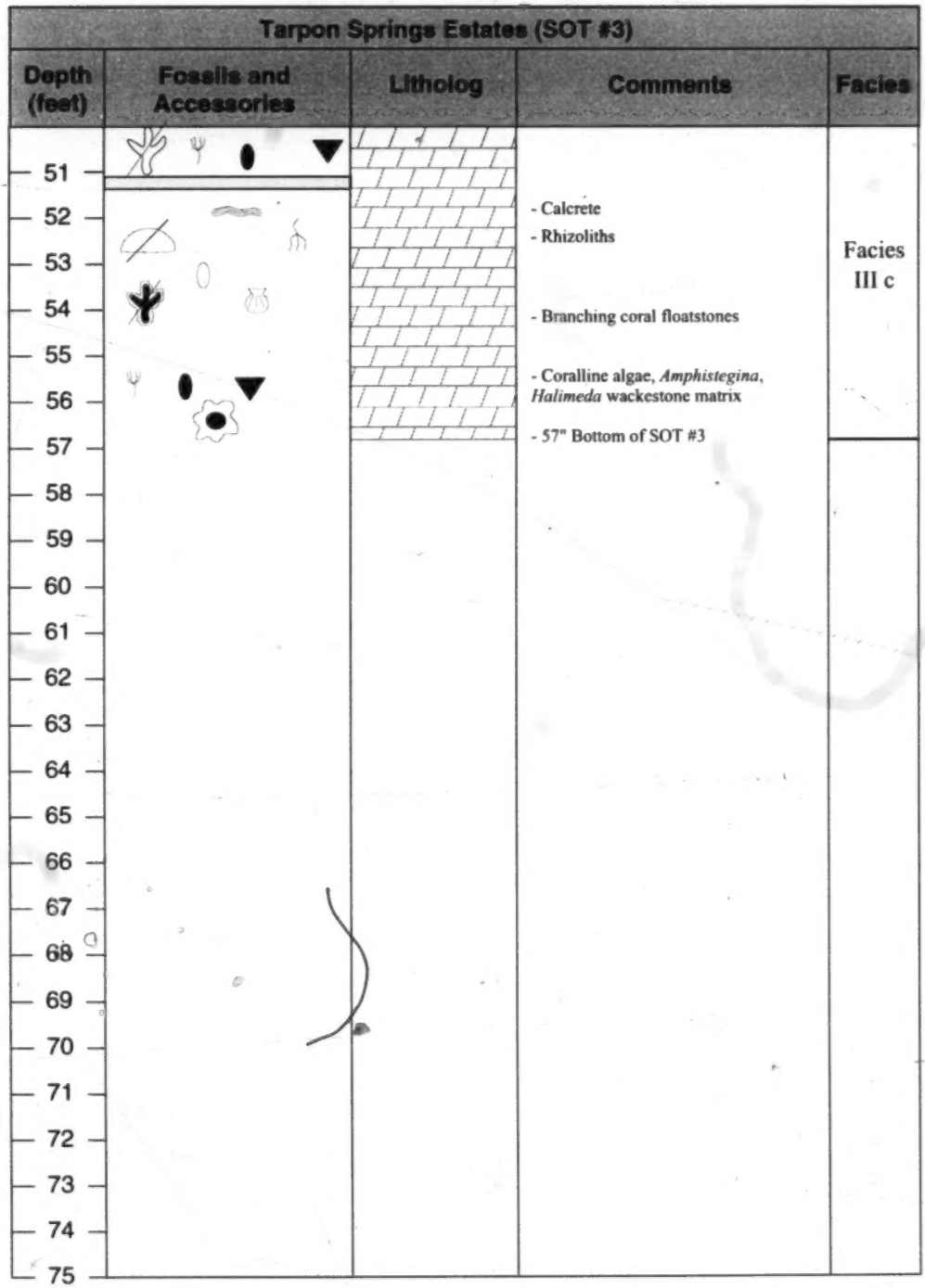
50
- Branching coral floatstones
- Coralline algae, Amphistegina, Halimeda wackestone matrix
- Gradational facies contact (28'10")
- Halimeda, coralline algae packstone and wackestone matrices
- Branching coral floatstones
- Gradational facies contact (34'4")
- Coralline algae, Amphistegina, Halimeda wackestone matrix
- Branching corals dominated by Stylophora
- Rare echinoid spines
- Calcrete
- Branching coral floatstones
- Coralline algae, Amphistegina, Halimeda wackestone matrix.
- Gradational facies contact (46'6")
- Massive coral floatstones
- Coraliine algae, Amphistegina, wackestone matrix
Facies III c
Facies III a
Facies III c
Facies III b


Tarpon Springs Estates (SOT #3)
Depth (feet)
Fossils and Accessories
Litholog
Comments
Facies
51
52
53
54
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56
57
58
59
60
61
62
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64
65
66
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68
69
70
71
72
73
74
75
- Calcrete
- Rhizoliths
- Branching coral floatstones
- Coralline algae, Amphistegina, Halimeda wackestone matrix
- 57" Bottom of SOT #3
Facies III c